



**Madoc Sewage Lagoon:
Performance, Opportunities,
and Recommendations:
Full Report**

Moira Lake Property Owners Association

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Madoc Sewage Lagoon: Performance, Opportunities, and Recommendations

Table of Contents

Executive Summary	5
1. Introduction	
1.1 Overview of Madoc Sewage Lagoon	8
1.2 Measurement Standards	8
1.3 Lagoon Operations Summary	9
2. Historic and Current Sewage Treatment Performance	
2.1 Carbonaceous Biochemical Oxygen Demand (CBOD5)	10
2.2 Total Suspended Solids (TSS)	13
2.3 Phosphorus	16
2.4 pH	18
2.5 Comparison of Upstream and Downstream Results	20
3. Stricter Performance Objectives	27
4. Gaps in the Current Testing Regime	
4.1 High Priority Gaps	
4.1.1 Nutrient Speciation and Eutrophication Risk	28
4.1.2 Pathogen Indicators	29
4.1.3 Groundwater Monitoring	29
4.1.4 Emerging Contaminants and Micropollutants	30
4.1.5 Provincial Water Quality Objectives Compliance	30
4.1.5 Dissolved Oxygen Monitoring	32
4.2 Medium Priority Gaps	
4.2.1 Ecological Impact Monitoring	33
4.2.2 Chlorophyll-a and Algal Biomass	33

4.3 Lower Priority Gaps	
4.3.1 Metals	34
4.3.2 Chemical Oxygen Demand (COD)	34
4.3.3 Enhanced Total Suspended Solids (TSS) Analysis	34
4.3.4 Toxicity Testing (e.g., Bioassays)	35
4.4 Gaps: Summary of Recommendations	35
5. Climate Risk Analysis & Adaptive Management	
5.1 Observed Climate Impacts on Lagoon Operations	37
5.1.1 Extreme Spring Flows	37
5.1.2 Misaligned Discharges	38
5.1.3 Effluent Temperature & Pathogen Survival	39
5.1.4 Hydrologic Stressors: Dilution Capacity & Stratification	40
5.1.5 Ecological Consequences: Species Shift in Moira Lake	40
5.2 Confirmation of Climate Impacts on Madoc Lagoon	41
5.3 Future Scenarios Under Climate Change	
5.3.1 2050s Wet Year Scenario	43
5.3.2 2050s Dry Year Scenario	44
5.3.3 Temperature Effects on Discharge Quality	44
5.4 Climate Adaptation Measures for Lagoon Operations	
5.4.1 Discharge Management	45
5.4.2 Influent Control	45
5.4.3 Pathogen & Temperature Mitigation	45
5.4.4 Monitoring Enhancements	46
5.4.5 Storage Planning	46
5.5 Summary of Key Climate Change Implications	47
5.6 Strategic Adaptation Actions	48
5.7 Conclusions: Ensuring Long-term Resilience	50
6. Observations of Lake Residents	51

7. Summary and Recommendations	52
8. Conclusion	56
9. Acknowledgments	57
10. References	58
11. Appendix 1: Examples of Stricter Performance Objectives	61
12. Appendix 2: Climate Change Impacts on Madoc Sewage Lagoon Performance	66
13. Appendix 3: Ontario Climate Context for Lagoon Discharge	72
14. Appendix 4: Glossary of Technical Terms	78

List of Figures

Figure 1. Location of Madoc Sewage Lagoon	9
Figure 2: CBOD5 Concentration for Spring & Fall Discharges (2018–2024)	12
Figure 3: TSS Concentration for Spring & Fall Discharges (2018–2024)	15
Figure 4: Phosphorus Concentration for Spring & Fall Discharges (2018–24)	17
Figure 5: Mean pH for Spring & Fall Discharges (2019–2024)	17
Figure 6: Upstream & Downstream CBOD5 Discharge Results (2018–2024)	22
Figure 7: Upstream & Downstream TSS Discharge Results (2018–2024)	24
Figure 8: Upstream & Downstream Phosphorus Results (2018–2024)	26

List of Tables

Table 1: Recommended Water Quality Parameters for Monitoring	36
Table 2: Confirmation of Climate Impacts on Madoc Lagoon	42
Table 3: Forward-Looking Climate Scenarios and Their Impacts on Lagoon Performance	43

Executive Summary

This report, prepared for the Moira Lake Property Owners Association (MLPOA), evaluates the performance and opportunities for improvement of the Madoc Sewage Lagoon, the primary wastewater treatment system for the Municipality of Centre Hastings. Discharging treated effluent into Deer Creek, which flows into Moira Lake—a sensitive ecosystem—the report highlights critical findings, identifies areas for improvement, and proposes actionable recommendations to enhance lagoon performance and address environmental and regulatory challenges.

The Madoc Sewage Lagoon operates under an Environmental Compliance Approval (ECA), which establishes effluent limits for key parameters such as Total Phosphorus (TP), Carbonaceous Biochemical Oxygen Demand (CBOD5), and Total Suspended Solids (TSS). The lagoon consistently meets these regulatory requirements, demonstrating effective operational performance. However, downstream water quality monitoring has revealed frequent exceedances of the Provincial Water Quality Objectives (PWQO) for TP and occasional exceedances for CBOD5, highlighting the lagoon’s contribution to nutrient enrichment in Deer Creek and downstream Moira Lake.

The PWQOs, established by the Ontario Ministry of the Environment, Conservation and Parks (MECP), serve as benchmarks for protecting aquatic ecosystems and recreational water quality.

Key Findings

- **Performance Metrics:** The lagoon demonstrates strong performance in meeting ECA discharge limits, reflecting effective operational management.
- **PWQO Exceedances:** Despite ECA regulatory compliance, downstream phosphorus levels frequently exceed PWQOs, contributing to nutrient enrichment and increased eutrophication risk in Deer Creek and Moira Lake. Occasional exceedances of CBOD5 PWQOs downstream suggest localized impacts on dissolved oxygen levels, particularly during high-flow spring discharges.
- **Community Concerns:** Residents report environmental degradation in Moira Lake, including algal blooms, weed growth, and sedimentation, suggesting a disconnect between compliance and public perception, necessitating improved communication and transparency.

- **Climate Change Impacts:** Climate change introduces challenges such as:
 - Increased nutrient loading from heavier rainfall.
 - Reduced dilution capacity during droughts.
 - Elevated effluent temperatures and prolonged pathogen survival.
 - Discharge timing complications during extreme weather events.

- **Testing Gaps:** The current testing regime focuses on basic parameters but omits some critical areas. Addressing these gaps is essential for protecting Moira Lake, preparing for future regulatory requirements, and meeting community expectations.
 - High-priority gaps include:
 - **Nutrient Speciation:** Monitoring bioavailable forms like Soluble Reactive Phosphorus (SRP) and nitrogen species to mitigate eutrophication risks.
 - **Pathogen Indicators:** Reintroducing testing for E. coli and Enterococci to ensure recreational water safety.
 - **Groundwater Monitoring:** Establishing semi-annual testing to detect potential seepage and protect local aquifers.
 - **Emerging Contaminants:** Implementing pilot testing for pharmaceuticals, microplastics, and endocrine disruptors to address long-term ecological risks.
 - **Adopting more stringent testing limits (e.g. PWQO and other standards)**
 - Medium-priority gaps include ecological monitoring and testing for algal indicators like chlorophyll-a, which provide insights into cumulative and long-term impacts.
 - Lower-priority gaps include metals monitoring, Chemical Oxygen Demand (COD) analysis, enhanced TSS fractionation, and toxicity testing, which refine treatment processes and optimize lagoon operations over time.

Opportunities for Improvement

1. **Adopt Stricter Performance Objectives:** Set more rigorous targets for CBOD5, TSS, pH, and phosphorus to reduce environmental impacts and prepare for evolving regulations. This is in line with leading best practices.
2. **Expand Monitoring:** Introduce testing for emerging contaminants, nutrient speciation, pathogen indicators, and algal biomass; implement toxicity and groundwater monitoring.
3. **Enhance Operations:** Investigate alternative conditioning strategies and implement automated process control and operating adjustments to stabilise performance.
4. **Engage the Community:** Improve transparency and involve stakeholders in system upgrades and stewardship efforts.
5. **Integrate Climate Resilience into Operations:** Upgrade hydraulic and storage capacity to manage variable flows, integrating adaptable treatment and buffering systems that function under changing seasonal and extreme-weather conditions. Include climate-sensitive parameters (e.g., temperature, conductivity) in long-term monitoring.

Conclusion

While the Madoc Sewage Lagoon currently meets ECA regulatory standards, emerging environmental pressures and community expectations require targeted improvements. By adopting stricter performance objectives, expanding monitoring, and enhancing community engagement, the Municipality of Centre Hastings can ensure sustainable, compliant, and environmentally responsible lagoon operations.

1. Introduction

The primary goals of this report, commissioned by the MLPOA, are:

- to assess the current performance of the Madoc Sewage Lagoon,
- identify opportunities for improvement in the monitoring processes,
- recommend improvements to align with emerging regulatory standards, address environmental concerns, and prepare for future challenges.

It also highlights a mis-alignment between residents' perceptions and the official perspective.

1.1 Overview of the Madoc Sewage Lagoon

The Municipality of Centre Hastings, in partnership with the Ontario Clean Water Agency (OCWA), operates the Madoc Wastewater Treatment Lagoon system as part of the municipal water and wastewater infrastructure. This facility plays a critical role in protecting local water quality and supporting the community's growth objectives.

The purpose of this section is to outline the standards, operational framework, and key performance metrics used to assess lagoon performance, with an emphasis on how these benchmarks align with regulatory requirements and the Municipality's environmental protection goals.

1.2 Measurement Standards

The Environmental Compliance Approval (ECA) and the Provincial Water Quality Objectives (PWQO) are two key regulatory tools used in Ontario to manage environmental quality, but they serve different purposes and operate within distinct frameworks.

The ECA is a legally binding document issued by the Ontario Ministry of the Environment, Conservation and Parks (MECP) that outlines the operational and discharge requirements for facilities like the Madoc Sewage Lagoon. It specifies permissible effluent limits for parameters such as Total Phosphorus (TP), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), and pH, ensuring that the facility operates in compliance with environmental regulations designed to protect local water bodies. ECA No. 1652-BRKT58 is the ECA applicable to the Madoc Sewage Lagoon.

The PWQO, on the other hand, is a set of non-enforceable guidelines established by the MECP to protect the quality of Ontario's surface water for aquatic life, recreation, and aesthetic purposes. For example, the PWQO sets a threshold for Total

Phosphorus of 0.03 mg/L in rivers to minimize the risk of excessive plant and algal growth, and 0.02 mg/L in lakes to prevent algal blooms. Unlike the ECA, which governs the operation of specific facilities, the PWQO provides broader benchmarks to evaluate the health of natural water bodies and assess cumulative impacts from multiple sources.

While the Madoc Sewage Lagoon consistently complies with its ECA limits, downstream monitoring in Deer Creek has shown frequent exceedances of PWQO guidelines for phosphorus and occasional exceedances for CBOD5.

This comparison highlights how the ECA ensures operational compliance for specific facilities, while the PWQO serves as a tool to assess the cumulative environmental impact of various nutrient sources, including the lagoon discharge, on aquatic ecosystems. Together, these tools complement each other by safeguarding both operational accountability and overall environmental health.

1.3 Lagoon Operations Summary

The Madoc Sewage Lagoon is a two-celled facultative lagoon system located just west of Highway 62 north of Moira Lake (Figure 1). The system serves the wastewater treatment needs of the Municipality of Centre Hastings.



Figure 1. Location of Madoc Sewage Lagoon

The lagoon plays a crucial role in the local community's environmental management, ensuring that wastewater is treated effectively before being discharged into the surrounding environment.

Facultative lagoons operate by leveraging natural biological processes. The system consists of different layers: the upper aerobic layer, where oxygen is present and supports aerobic bacteria, and the lower anaerobic layer, where organic material is broken down by anaerobic bacteria. The middle layer transitions between these two zones. This stratification allows for effective treatment of wastewater, reducing harmful pollutants before discharge.

Over the years, the Madoc Sewage Lagoon has consistently met its regulatory ECA requirements for treating sewage. The treatment processes in the lagoon remove organic matter, nutrients like phosphorus, and suspended solids, ensuring that the effluent is safe for discharge into nearby water bodies, including Deer Creek and Moira Lake.

The lagoon is designed with a capacity to handle approximately 1,008 cubic meters of wastewater per day. It operates on a seasonal discharge cycle, with two major discharge periods: one in the spring and one in the fall. During these periods, treated effluent is released into Deer Creek after meeting water quality parameters, such as pH, carbonaceous biochemical oxygen demand (CBOD5), total suspended solids (TSS), and phosphorus concentrations.

In recent years, the lagoon's performance has been evaluated through regular monitoring and annual reports, highlighting its success in maintaining effluent quality within regulatory limits. This report will further explore the lagoon's historical performance (2018 – 2024), challenges faced, and potential improvements to ensure it continues to meet the growing demands of the community and regulatory standards.

2. Historic and Current Sewage Treatment Performance

Regulatory limits quoted in this section are from the Ministry of the Environment, Conservation and Parks (MECP), Environmental Compliance Approvals for Madoc Sewage Lagoons (ECA No. 1652-BRKT58). For comparison purposes PWQO guidelines are noted on the charts and in discussions.

2.1 Carbonaceous Biochemical Oxygen Demand (CBOD5)

The Madoc Sewage Lagoon consistently meets ECA regulatory limits for carbonaceous biochemical oxygen demand (CBOD5), a key indicator of the effectiveness of biological treatment in breaking down organic matter in wastewater. CBOD5 measures the amount of oxygen microorganisms need to degrade organic

pollutants in the water. Lower CBOD5 levels indicate more efficient treatment and reduced organic material in the effluent, which is crucial for protecting the receiving water body such as Moira Lake.

2.1.1 Performance

The ECA regulatory limit for CBOD5 in treated effluent is 30 mg/L, with a performance objective target of 25 mg/L. Over the past several years, the Madoc Sewage Lagoon has had a downward trend in CBOD5 concentration and consistently maintained CBOD5 levels within the ECA regulatory limits (Figure 2), demonstrating that the biological processes in the lagoon are functioning as expected.

However, spring and fall CBOD5 averages consistently exceed the PWQO guideline, indicating that while the lagoon meets its ECA compliance limits, its effluent may still contribute to elevated CBOD5 levels (oxygen demand) in receiving waters such as Deer Creek and Moira Lake.

2.1.2 Impact of CBOD5 Levels on Treatment Performance

CBOD5 is a direct measure of the organic load in wastewater and reflects how much oxygen is required to biologically degrade the organic matter. When CBOD5 levels are low, it indicates that the lagoon's biological processes are functioning efficiently. Effective CBOD5 removal helps reduce oxygen demand in the receiving water bodies, protecting aquatic ecosystems.

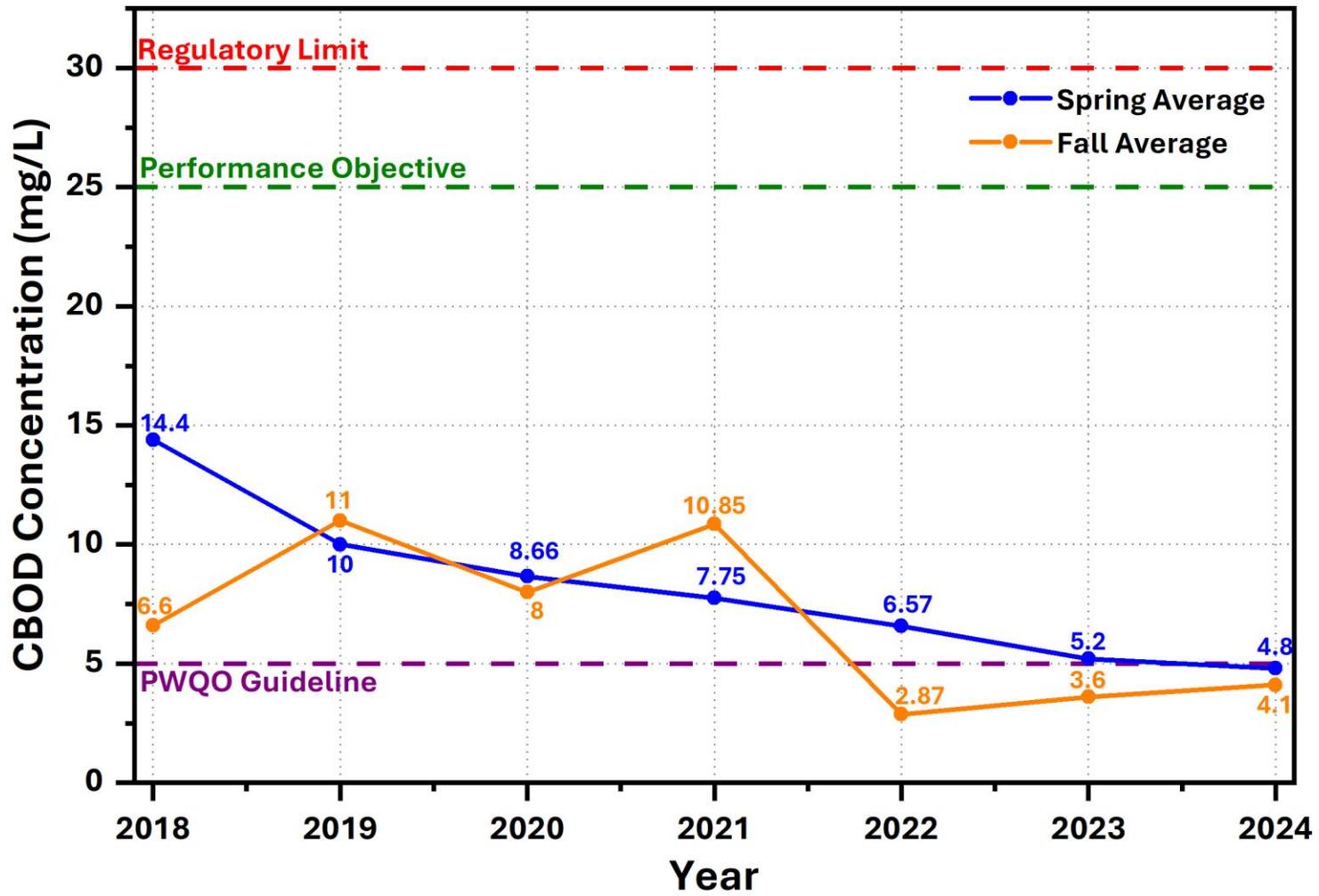


Figure 2. Average CBOD5 Concentration for Spring and Fall Discharges, 2018 – 2024
 (References: Madoc Sewage Lagoon Annual Reports 2018 to 2024)

2.1.3 Improving CBOD5 Levels

Several strategies can be implemented to further improve CBOD5 removal:

- **Optimize Aeration:** Increase oxygen supply for better bacterial activity.
- **Increase Retention Time:** Allow more time for microbial degradation.
- **Improve Sludge Management:** Regularly remove sludge to maintain microbial efficiency.
- **Enhance Mixing and Temperature:** Ensure proper oxygen distribution and maintain favorable temperatures.
- **Use Bioaugmentation:** Add specialized bacteria to accelerate organic breakdown.
- **Pre-Treat Influent:** Remove organic matter before it enters the lagoon.
- **Optimize Nutrients:** Maintain proper nitrogen and phosphorus balance to support microbial processes.

Source: United States Environmental Protection Agency (EPA). Primer for Municipal Wastewater Treatment Systems

2.2 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) refers to particles suspended in wastewater, such as organic and inorganic matter, that impact water clarity and quality. High TSS levels can lead to sedimentation and habitat degradation in receiving water bodies, making TSS an important parameter to monitor and control.

2.2.1 Performance

The ECA regulatory limit for TSS in treated effluent is 30 mg/L, with a performance objective of 25 mg/L. PWQO guidelines are the same as the ECA performance objective level. The Madoc Sewage Lagoon has consistently kept TSS levels within acceptable ECA regulatory ranges across all years and discharge periods (spring and fall), ensuring that the effluent does not negatively affect the receiving water bodies (Figure 3).

2.2.2 Impact of TSS Levels on Treatment Performance

TSS levels indicate how well solids are being removed from the wastewater. Lower TSS levels mean that suspended solids are being efficiently settled or removed, which prevents excessive sedimentation in receiving water bodies. Proper TSS

management also improves the overall water quality and helps protect downstream ecosystems.

2.2.3 Improving TSS Levels

To further improve TSS removal, the following strategies can be implemented:

- **Optimize Sedimentation:** Enhance sedimentation by improving lagoon flow patterns or adding settling aids.
- **Improve Sludge Management:** Regular removal of sludge to prevent re-suspension of solids.
- **Increase Retention Time:** Allow more time for solids to settle.
- **Enhance Mixing:** Prevent short-circuiting to ensure effective solid settling.
- **Upgrade Lagoon Design:** Add baffles or flow control mechanisms to improve sedimentation efficiency.

Source: United States Environmental Protection Agency (EPA). Primer for Municipal Wastewater Treatment Systems

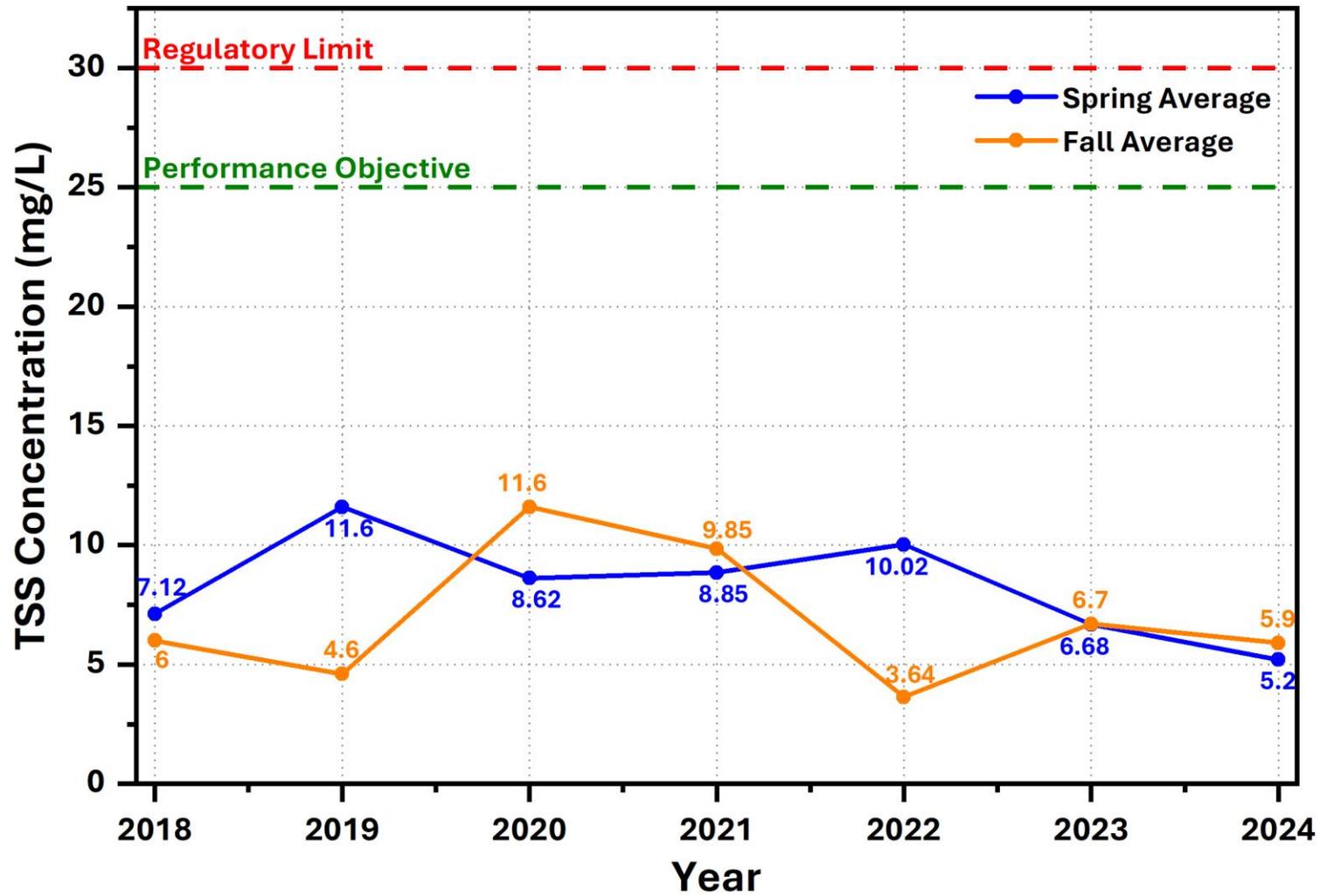


Figure 3. Average TSS Concentration for Spring and Fall Discharges, 2018 – 2024
 (References: Madoc Sewage Lagoon Annual Reports 2018 to 2024)

2.3 Phosphorus

Phosphorus is a key nutrient that contributes to eutrophication—the excessive growth of algae and aquatic plants in receiving water bodies. Elevated phosphorus levels lead to oxygen depletion and disrupt aquatic ecosystems. Proper phosphorus management is essential for protecting downstream water bodies such as Moira Lake.

2.3.1 Performance

The ECA regulatory limit for phosphorus in effluent is 0.5 mg/L, with a performance objective target of 0.3 mg/L.

The Phosphorus ECA Regulatory Limit is consistently met for both spring and fall discharges from 2018 to 2024. The ECA performance objective is also met for most years. However, fall discharge in 2021 (0.22 mg/L) approached the ECA performance objective. All spring discharges remain well below the ECA performance objective.

The PWQO guideline for rivers (0.03 mg/L) and eutrophic lakes (0.02 mg/L) are exceeded in most years. Fall concentrations in 2019 (0.034 mg/L) and 2021 (0.22 mg/L) exceed the PWQO guideline for rivers. Both spring and fall discharges consistently exceed the PWQO guideline for lakes of 0.02 mg/L (Figure 4).

While the lagoon's discharges comply with ECA regulatory limits and generally meet ECA performance objectives, they regularly exceed the stricter PWQO guidelines for both rivers and lakes.

This suggests that while the lagoon performs well from an ECA regulatory perspective, its discharges still contribute to downstream nutrient enrichment and potential environmental impacts in Deer Creek and Moira Lake.

2.3.2 Impact of Phosphorus Levels on Treatment Performance

Low phosphorus levels are crucial to prevent nutrient overloading in receiving water bodies, which could lead to eutrophication. Proper phosphorus management in the lagoon helps maintain the ecological balance in downstream ecosystems and ensures compliance with environmental standards.

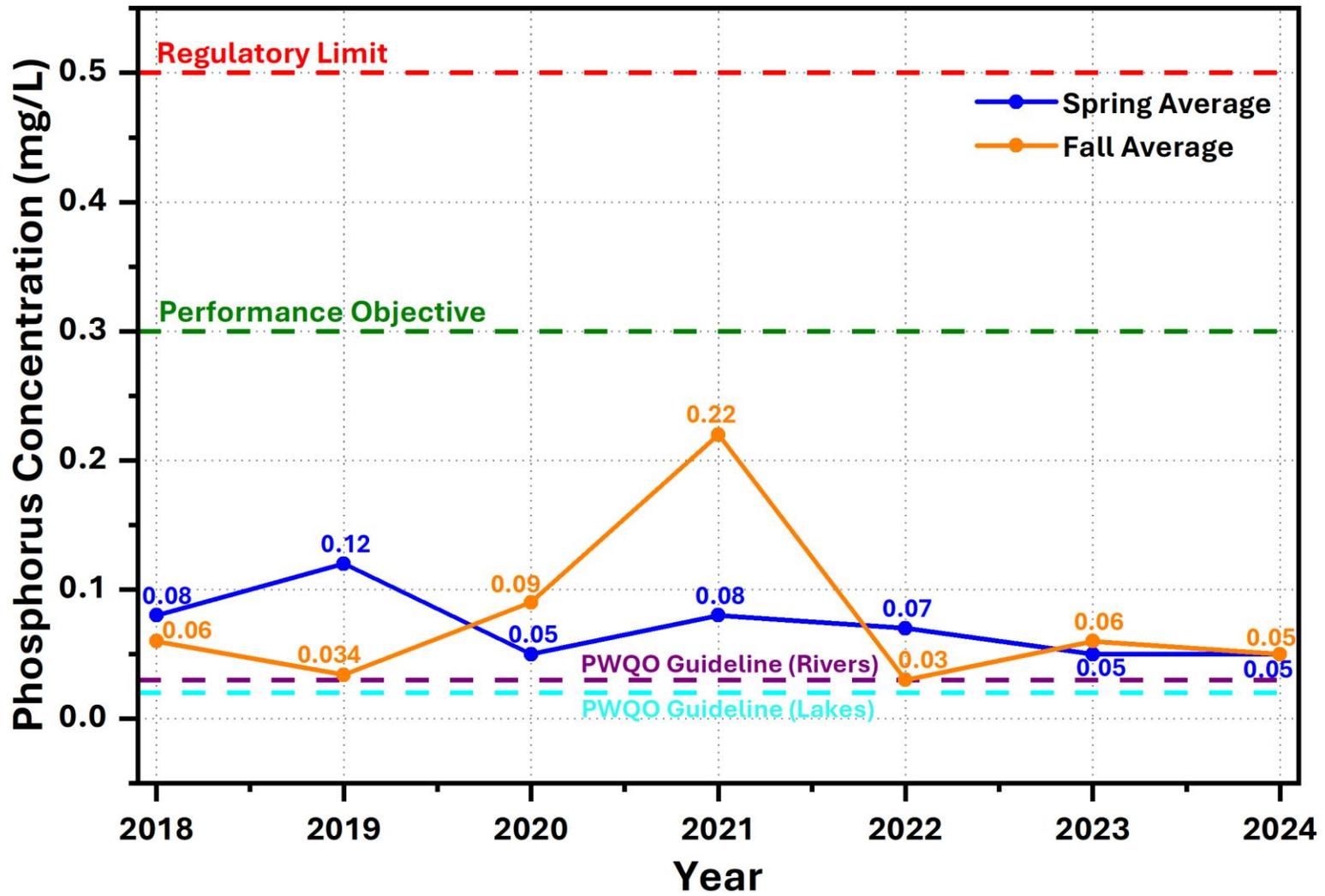


Figure 4. Average Phosphorus Concentration for Spring and Fall Discharges, 2018 – 2024
 (References: Madoc Sewage Lagoon Annual Reports 2018 to 2024)

2.3.3 Improving Phosphorus Levels

To further improve phosphorus removal, the following strategies can be implemented:

- **Optimize Alum Dosing:** Increase or fine-tune alum dosing to enhance phosphorus binding and removal.
- **Improve Sludge Management:** Regular removal of sludge to prevent phosphorus re-release into the water column.
- **Enhance Sedimentation:** Improve sedimentation processes to capture and settle phosphorus more effectively.
- **Increase Retention Time:** Extend the retention period to allow more time for phosphorus to settle out of the water column.
- **Pre-Treatment of Influent:** Implement pre-treatment processes to reduce phosphorus concentrations before wastewater enters the lagoon.

Source: United States Environmental Protection Agency (EPA). Primer for Municipal Wastewater Treatment Systems.

2.4 pH

pH is a critical water quality parameter that measures the acidity or alkalinity of the wastewater. pH influences the efficiency of biological treatment processes in the lagoon and affects the quality of the effluent. Proper pH management ensures that the effluent is safe for discharge and does not harm aquatic ecosystems.

2.4.1 Performance

The acceptable ECA regulatory pH range for effluent discharge is between 6.0 to 9.5 with an ECA performance objective range of 6.5 to 8.5. Across all years and discharge periods (spring and fall), the pH values of the Madoc Sewage Lagoon remained within both the regulatory limits and the performance objective range (Figure 5). This indicates that the lagoon is functioning properly in terms of pH control, preventing harmful pH fluctuations that could affect the receiving water body. For pH the PWQO the guideline range is the same as the ECA performance objective.

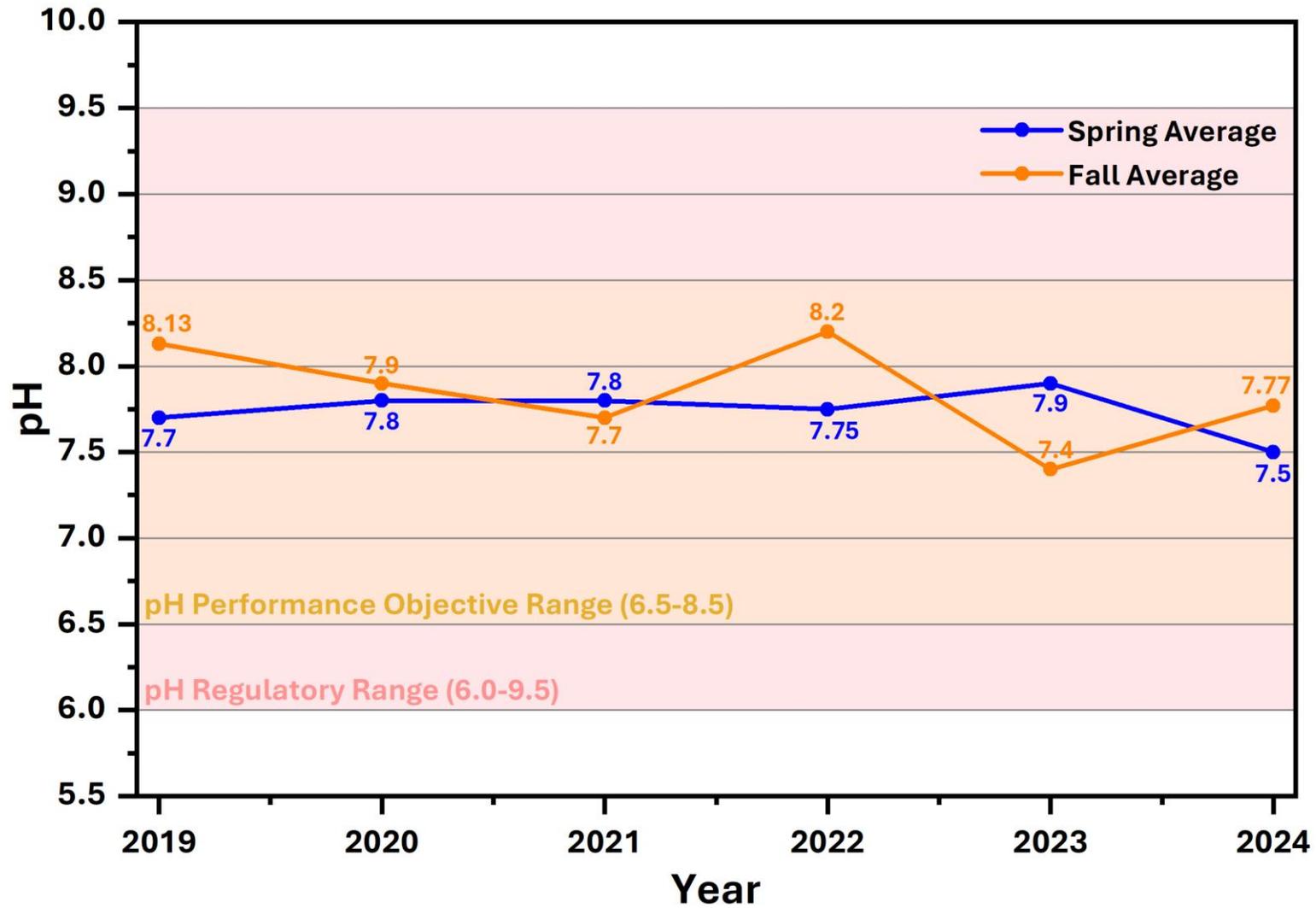


Figure 5. Mean pH for Spring and Fall Discharges, 2019 – 2024
 (References: Madoc Sewage Lagoon Annual Reports 2018 to 2024)

2.4.2 Impact of pH Levels on Treatment Performance

Maintaining pH levels within the desired range is essential for the lagoon's biological processes, which rely on stable pH conditions for the optimal activity of microorganisms. Stable pH levels prevent the effluent from being too acidic or too alkaline, reducing the potential for harmful effects on downstream aquatic ecosystems.

2.4.3 Improving pH Management

To maintain and improve pH management, the following strategies can be implemented:

- **Optimize Chemical Dosing:** Fine-tune chemical dosing to stabilize pH levels and prevent fluctuations.
- **Monitor pH Regularly:** Increase the frequency of pH monitoring to detect and correct deviations promptly.
- **Enhance Mixing:** Ensure that mixing is adequate to avoid localized pH imbalances.
- **Pre-Treat Influent:** Use pre-treatment methods to balance the pH of influent wastewater before it enters the lagoon.

Source: United States Environmental Protection Agency (EPA). Primer for Municipal Wastewater Treatment Systems.

2.5 Comparison of Upstream and Downstream Results

Monitoring upstream and downstream water quality helps assess the impact of the lagoon's effluent on receiving water bodies, such as Deer Creek and Moira Lake, during both the spring and fall discharge periods.

2.5.1 Performance

General Performance

The Madoc Sewage Lagoon's effluent shows downstream water quality parameters remaining within acceptable ECA ranges. However, CBOD5 and Phosphorous levels occasionally exceed the PWQO guidelines.

The charts below suggest that 2023, particularly the spring, was an atypical year across multiple parameters (CBOD5, TSS, and Total Phosphorus) with higher-than-normal levels downstream. This might point to operational or environmental factors influencing treatment effectiveness. Reviewing treatment operations or changes in

influent quality for 2023 could help pinpoint why these values increased, especially downstream.

Carbonaceous Biochemical Oxygen Demand (CBOD5)

CBOD5 levels upstream are relatively stable across years and seasons, mostly around 4-5 mg/L, well below ECA limits (Figure 6).

Most upstream CBOD5 levels remain below the PWQO guideline of 5 mg/L, indicating minimal organic loading from natural or upstream sources

Most upstream CBOD5 levels remain below the PWQO guideline of 5 mg/L, indicating minimal organic loading from natural or upstream sources.

Downstream CBOD5 levels occasionally exceed the PWQO guideline, particularly during specific seasons, such as 2023 Spring and Fall, where downstream levels are notably higher compared to upstream values.

The downstream increases in CBOD5 concentrations relative to upstream indicate the lagoon's discharge contributes organic matter, which could elevate oxygen demand in receiving waters.

While levels remain below ECA regulatory limits, downstream exceedances of the PWQO are environmentally significant and warrant attention. Elevated CBOD5 downstream could lead to reduced dissolved oxygen levels, particularly during warmer months when oxygen depletion risks are higher due to increased microbial activity.

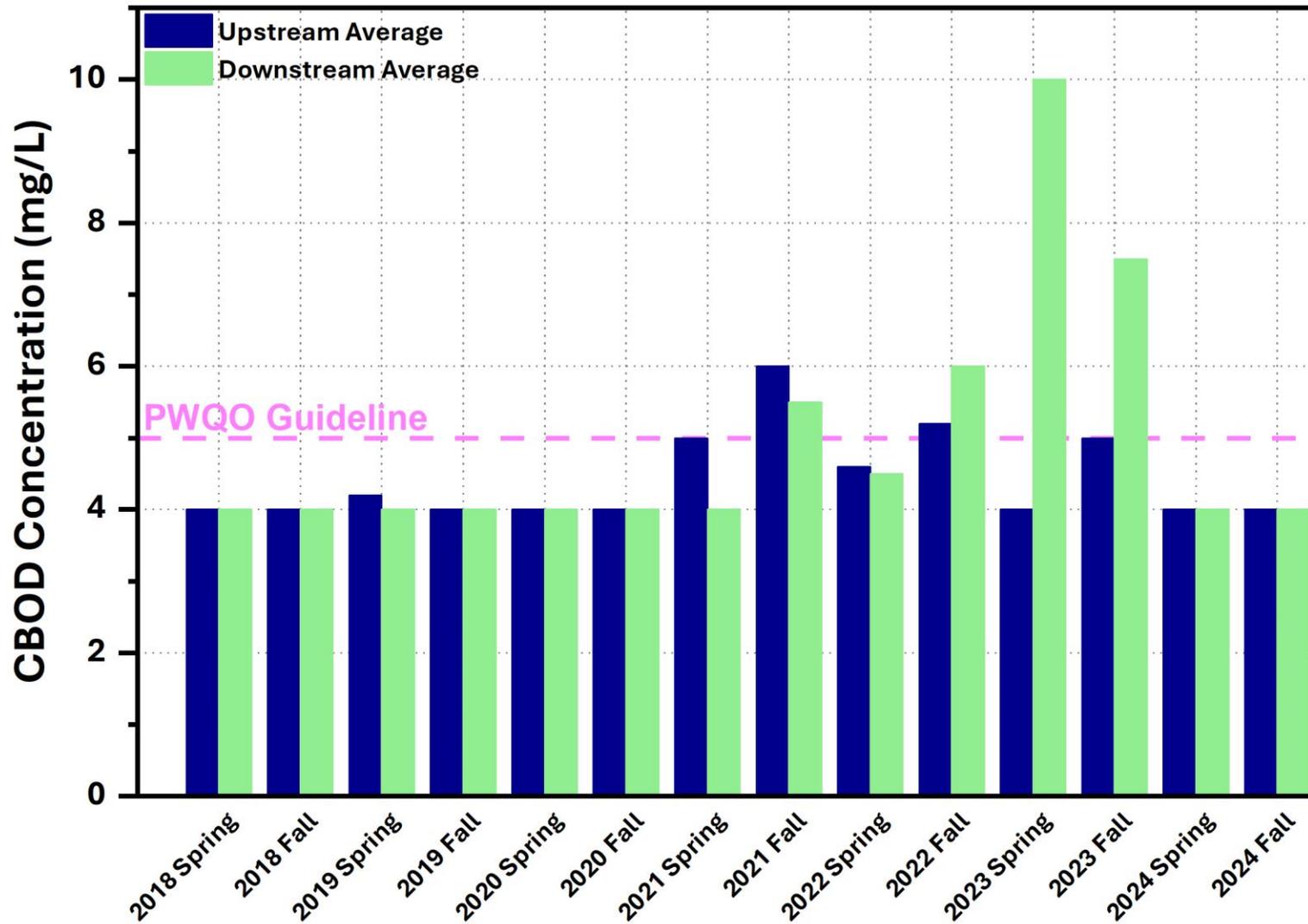


Figure 6. Upstream & Downstream CBOD5 Discharge Results (2018 – 2024)
 (References: Madoc Sewage Lagoon Annual Reports 2018 to 2024)

Total Suspended Solids

TSS levels in this time period were below ECA limits and also below PWQO guidelines (Figure 7).

However, the data from 2021 to 2024 for upstream TSS shows an upward trend in both spring and fall. In the spring of 2021, the upstream TSS started at 2.5 mg/L and rose to 9.3 mg/L by spring 2023. Similarly, fall data increased from 4.5 mg/L in 2021 to 8.2 mg/L in 2023.

The increase in TSS during the spring of 2023 is particularly significant, indicating a sharp rise compared to previous years. This could signal environmental changes such as heavy rainfall or increased erosion upstream.

The downstream TSS data also show an increasing trend but at a more moderate rate compared to upstream. In the spring of 2021, TSS was at 2.5 mg/L and increased to 5.2 mg/L by spring 2023. Fall TSS levels rose from 5 mg/L in 2021 to 6.5 mg/L in 2023.

The downstream location typically benefits from natural settling and treatment processes in the lagoon, which may explain the slightly lower increase rate compared to upstream. However, the upward trend is still concerning as it indicates increasing dissolved solids entering Moira Lake. Elevated TSS levels downstream could reduce light penetration and affect aquatic vegetation growth, and transport attached nutrients, such as phosphorus, which could enhance eutrophication risks in Deer Creek and downstream water bodies.

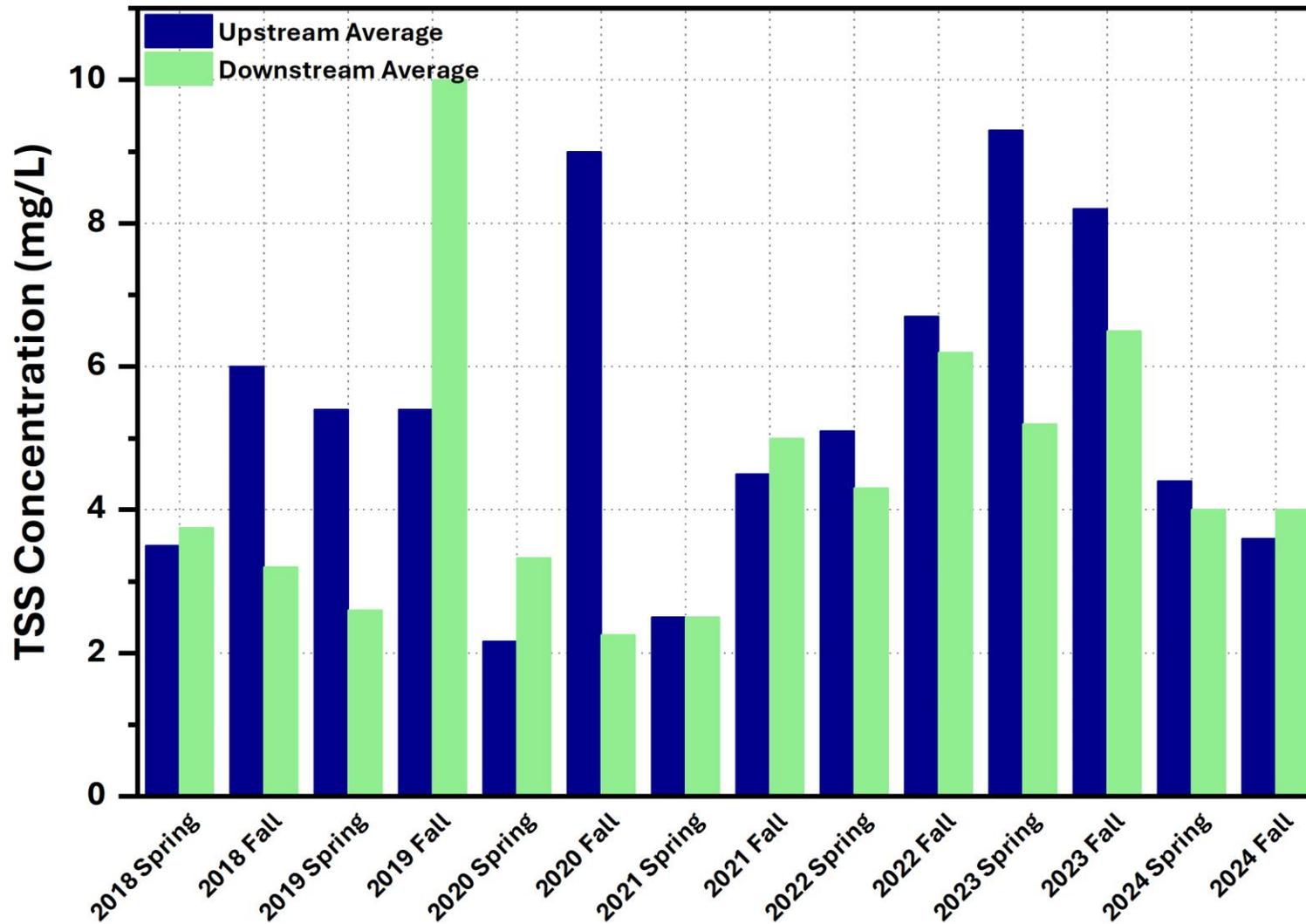


Figure 7. Upstream & Downstream TSS Discharge Results (2018 – 2024)
 (References: Madoc Sewage Lagoon Annual Reports 2018 to 2024)

Phosphorous

Upstream and downstream phosphorous levels consistently meet ECA limits (Figure 8).

Upstream phosphorus levels are consistently stable, around 0.03-0.04 mg/L. The most striking observation is the substantial increase in downstream phosphorus levels in the spring of 2023, reaching 0.22 mg/L. This is significantly higher than both the upstream levels and the typical downstream concentrations observed in other years.

Most upstream values align with or slightly exceed the PWQO for rivers. While downstream values frequently exceed the PWQO for rivers (0.03 mg/L) and lakes (0.02 mg/L), even in non-spike years, the pattern is consistent and unequivocal. The 2023 spring spike is a notable outlier, reaching levels significantly beyond typical seasonal variations. Its impacts are not transient; a surge of that magnitude can embed itself in sediment–water feedback loops, prolonging elevated phosphorus release for years.

Downstream phosphorus increases demonstrate the lagoon’s impact, with contributions often sufficient to push levels above the PWQO, particularly for lakes. High phosphorus concentrations, particularly downstream, lead to nutrient enrichment in receiving waters, increasing the risk of algal blooms and subsequent oxygen depletion, which can harm aquatic ecosystems. This is particularly true of Moira Lake, where the combination of downstream loading and long residence times makes the system especially vulnerable to multi-year ecological consequences once a major phosphorus pulse enters the basin.

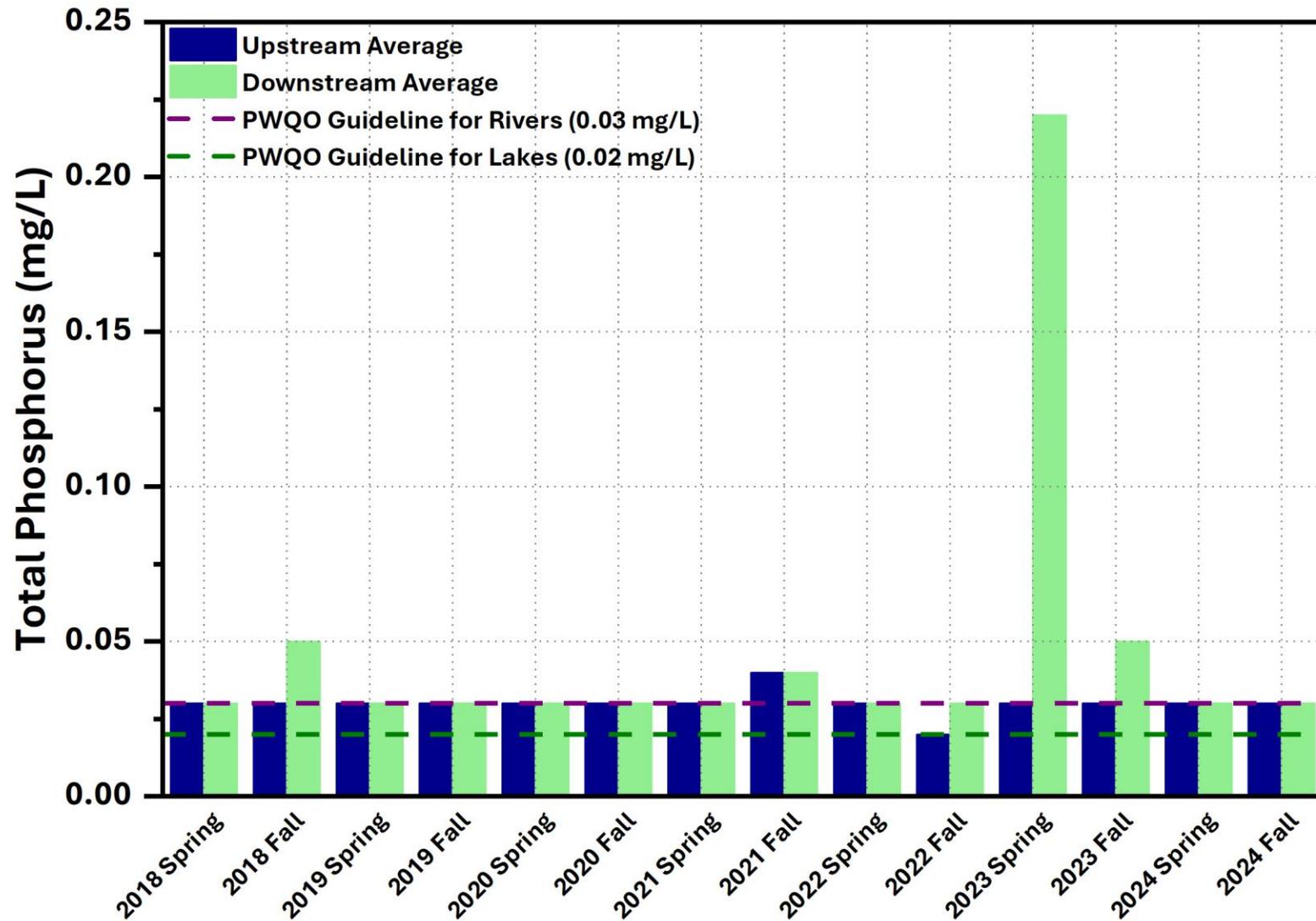


Figure 8. Upstream & Downstream Phosphorous Discharge Results (2018 – 2024)
 (References: Madoc Sewage Lagoon Annual Reports 2018 to 2024)

3. Stricter Performance Objectives

While the Performance Objectives for existing ECA metrics currently maintain compliance, the potential for future regulatory tightening, especially concerning nutrient and suspended solids limits, suggests that adopting more stringent performance objectives now could help mitigate future compliance risks and enhance environmental protection.

Other jurisdictions have already adopted stricter performance objectives for sensitive waters like Deer Creek and Moira Lake. For Example:

1. EU standards typically require CBOD5 limits at 25 mg/L for secondary treatment, with lower targets around 15 mg/L for high-risk waters or protected environments.
2. In California, USA, some regions enforce TSS limits as low as 10 mg/L, especially in areas where effluent is discharged into water bodies that support recreational activities or aquatic ecosystems sensitive to sedimentation.
3. In Alberta, Canada, phosphorus limits can be as low as 0.1 mg/L for discharge into ecologically sensitive areas or nutrient-rich lakes.

See Appendix 1 for further examples and citations for stricter performance objectives.

If stricter limits for nutrients and suspended solids were adopted, the Madoc Sewage Lagoon would be operating close to its treatment capacity and would only just meet the new standards. This shows that setting tougher performance goals now would help reduce future compliance risks and protect downstream water quality.

4. Gaps in the Current Testing Regime

The Madoc Sewage Lagoon's current testing framework ensures compliance with ECA No. 1652-BRKT58 standards by monitoring Carbonaceous Biochemical Oxygen Demand, Total Suspended Solids, total phosphorus, and pH levels. While these metrics address immediate regulatory requirements, they do not capture the full range of environmental impacts or prepare the system for emerging challenges. Addressing the following gaps will improve the lagoon's ability to protect downstream ecosystems, meet evolving regulatory standards, and address community concerns.

4.1 High-Priority Gaps

High-priority gaps represent the most immediate needs for protecting public health, safeguarding sensitive ecosystems, and preparing for stricter regulations.

4.1.1 Nutrient Speciation and Eutrophication Risk

Although the lagoon testing currently monitors total phosphorus levels to comply with regulatory limits, focusing solely on this metric may overlook certain aspects of nutrient dynamics that contribute to eutrophication in downstream water bodies like Deer Creek and Moira Lake. Nutrient Speciation is the identification and measuring of the different chemical forms, or "species," of nutrients.

Current Practice: Total phosphorus testing aggregates all forms of phosphorus but does not differentiate bioavailable forms like Soluble Reactive Phosphorus (SRP), which directly contribute to eutrophication. Similarly, nitrogen species, including ammonia, nitrate, and nitrite, are unmonitored. This is a serious deficiency.

Risks: SRP is readily absorbed by algae and aquatic plants, fueling blooms that disrupt aquatic ecosystems and deplete oxygen levels. Ammonia is toxic to fish at high concentrations, while nitrate and nitrite contribute to nutrient overloading and degrade water quality in Moira Lake.

Regulatory Context: Many jurisdictions now require SRP monitoring to better manage eutrophication risks. Monitoring is standard in regions with nutrient-sensitive water bodies. Interest in SRP monitoring is rising, with potential provincial regulations a possibility in the not-so-distant future.

Proposed Enhancements: Add SRP testing to quantify bioavailable phosphorus. Incorporate nitrogen speciation (ammonia, nitrate, nitrite) to assess overall nutrient contributions and risks.

Benefits: Improved understanding of nutrient dynamics will enable targeted interventions to mitigate algal blooms and downstream eutrophication.

4.1.2 Pathogen Indicators

Current Practice: Pathogen testing of effluent, including E. coli and Enterococci, ceased in 2018.

Risks: Without monitoring, the safety of recreational waters in Moira Lake cannot be guaranteed. Contaminated water poses risks to public health, particularly during discharge periods.

Regulatory Context: Monitoring for microbial pathogens is a core requirement in recreational water quality guidelines and is widely implemented in similar wastewater systems.

Proposed Enhancements: Reintroduce routine pathogen testing, focusing on E. coli and Enterococci, particularly during discharge periods.

Benefits: Enhanced protection for public health and increased transparency in addressing community concerns.

4.1.3 Groundwater Monitoring

Current Practice: No groundwater monitoring is conducted near the lagoon.

Risks: Potential seepage of nutrients or pathogens could contaminate local aquifers, posing risks to drinking water and the environment.

Regulatory Context: Groundwater monitoring is a key component of Ontario's source water protection initiatives.

Proposed Enhancements: Establish semi-annual groundwater monitoring, testing for nitrates, phosphorus, and microbial indicators.

Benefits: Early detection of seepage risks will protect local aquifers and ensure compliance with source water protection policies. Groundwater monitoring around sewage lagoons is an essential practice for maintaining environmental integrity, protecting public health. Monitoring around lagoons helps ensure that any potential seepage does not introduce harmful substances into the local groundwater, protecting the quality of nearby wells and water sources and ensuring compliance with regulations. Monitoring is particularly important for rural or environmentally sensitive areas where groundwater flows can influence larger bodies of water, such as Deer Creek

and Moira Lake. Implementing such measures would align with best practices for environmental protection in wastewater management.

4.1.4 Emerging Contaminants

Emerging contaminants, including pharmaceuticals, personal care products, microplastics, and industrial chemicals, are an increasing concern in wastewater management due to their potential long-term environmental and health impacts. These substances are often not fully removed by conventional wastewater treatment processes and can persist in effluent discharged into natural water bodies.

Current Practice: Testing excludes micropollutants such as pharmaceuticals, personal care products, microplastics, and endocrine-disrupting chemicals.

Risks: These substances persist in the environment, accumulate in wildlife, and disrupt aquatic ecosystems. Their presence in effluent is an emerging concern globally.

Regulatory Context: International regulations, including those from the EU and US EPA, increasingly require monitoring for emerging contaminants.

Proposed Enhancements: Pilot testing for pharmaceuticals, endocrine disruptors, and microplastics to identify risks and prepare for future regulations.

Benefits: Proactive monitoring will position the lagoon for compliance with anticipated standards and reduce long-term environmental risks.

4.1.5 PWQO Compliance

Effluent from the Madoc Sewage Lagoon consistently meets its Environmental Compliance Approval (ECA) limits for Total Phosphorus (TP), Carbonaceous Biochemical Oxygen Demand (CBOD5), and Total Suspended Solids (TSS). However, downstream water quality monitoring in Deer Creek reveals that concentrations of TP and CBOD5 often exceed the Provincial Water Quality Objectives (PWQO) for rivers and lakes.

Current Practice: Focus on ECA regulations only.

Risks: The frequent exceedance of PWQO guidelines downstream poses risks to aquatic ecosystems, including: eutrophication, oxygen depletion, and

regulatory non-alignment (while the lagoon complies with ECA limits, PWQO exceedances highlight a broader environmental concern, potentially affecting long-term ecosystem health and compliance with provincial water quality expectations).

Regulatory Context: The Provincial Water Quality Objectives (PWQOs) are non-enforceable benchmarks established by the Ontario Ministry of the Environment, Conservation and Parks (MECP) to maintain the health of aquatic ecosystems.

Proposed Enhancements: To address PWQO exceedances, the following actions are recommended:

- Effluent Quality Optimization:
 - Enhance phosphorus and organic matter removal processes to achieve effluent concentrations more closely aligned with PWQO guidelines, even though the ECA limits are less stringent.
 - Explore tertiary treatment options, such as chemical precipitation or constructed wetlands, to further reduce phosphorus levels.
- Enhanced Monitoring:
 - Increase the frequency of upstream and downstream water quality monitoring, particularly for phosphorus and CBOD5, to track progress toward PWQO alignment and assess cumulative impacts.

Benefits:

- Ecosystem Health: Improved effluent quality will reduce nutrient loading and oxygen depletion in Deer Creek, promoting a healthier aquatic ecosystem.
- Regulatory Alignment: Aligning discharge practices with PWQO guidelines demonstrates environmental responsibility and commitment to provincial water quality goals.
- Stakeholder Confidence: Proactively addressing PWQO exceedances builds trust with regulators, local communities, and other watershed stakeholders.

4.1.6 Dissolved Oxygen Monitoring (DO)

Current Practice: Dissolved oxygen (DO) is not currently monitored in either final effluent or downstream waters. This omission limits the ability to detect hypoxia or assess discharge impacts on sensitive receiving environments like Moira Lake.

Risks: Without DO data, the lagoon's role in exacerbating low-oxygen conditions cannot be assessed. Hypoxia also promotes internal phosphorus loading and harms aquatic habitat.

Regulatory Context: DO monitoring is not required under the current ECA. However, Ontario's Surface Water Quality Objectives recommend a minimum of 5 mg/L DO to protect warm-water species. MECP best practices increasingly support DO monitoring where eutrophication or discharge timing could affect oxygen levels.

Proposed Enhancements:

- Add portable or continuous DO monitoring during all discharge events.
- Monitor at both the final effluent outlet and a key downstream site (e.g., Moira Lake or Deer Creek).
- Conduct spot checks during non-discharge periods to understand background DO dynamics.

Benefits:

- Detects hypoxia early and supports adaptive discharge decisions.
- Verifies environmental performance and discharge timing.
- Aligns with provincial objectives and evolving regulatory expectations.

4.2 Medium-Priority Gaps

Medium-priority gaps address cumulative and long-term ecosystem impacts, providing data to guide sustainable management practices.

4.2.1 Ecological Monitoring

Current Practice: Monitoring focuses solely on effluent quality without assessing downstream biological or ecological impacts.

Risks: Cumulative effects of discharges on biodiversity, fish populations, and aquatic habitats remain unknown.

Proposed Enhancements: Implement a biological monitoring program in partnership with local environmental agencies, focusing on indicators like benthic invertebrate diversity, fish health, and algal presence. This will help in understanding the long-term ecological effects of lagoon discharge and identifying any emerging stressors on aquatic ecosystems.

Benefits: Improved understanding of how effluent impacts aquatic ecosystems over time will inform adaptive management strategies.

4.2.2 Chlorophyll-a and Algal Biomass

Current Practice: The current testing protocol does not include testing for Chlorophyll-a. Measuring chlorophyll-a levels in water is a common way to estimate algal biomass, or the amount of algae present in a water body. High levels of chlorophyll-a typically indicate an abundance of algae, which can be a sign of nutrient enrichment or eutrophication in the water.

Risks: Algal blooms linked to nutrient enrichment may go undetected until they visibly degrade water quality.

Proposed Enhancements: Measure chlorophyll-a concentration or algal biomass as a proxy for nutrient enrichment. These should be conducted during the discharge season especially if the receiving water body shows visible algal growth.

Benefits: This testing acts as an early warning system for potential eutrophication issues and allows for proactive nutrient management to reduce impacts on aquatic life.

4.3 Lower-Priority Gaps

Lower-priority gaps provide supplementary data and insights to refine operational practices and optimize treatment processes.

4.3.1 Metals Monitoring

Current Practice: Based on observations in OCWA Annual Reports, effluent is not analyzed for aluminum, iron, or manganese, despite their relevance to alum dosing and sediment chemistry.

Risks: Unmonitored metals may accumulate in sediments, potentially affecting benthic organisms and water quality.

Proposed Enhancement: Implement effluent testing for aluminum, iron and manganese. Since alum is used in phosphorus removal, monitoring aluminum concentrations in the effluent could help ensure it remains within safe levels for aquatic environments. Similarly, other metals like iron and manganese may be present from sediment or stormwater inputs and could accumulate in lagoon sediments or affect water quality downstream.

Benefits: These tests ensure that metals from the treatment process or from stormwater inflows do not reach harmful levels in the discharge, helping to protect aquatic life and avoid potential sediment accumulation issues.

4.3.2 Chemical Oxygen Demand (COD)

Current Practice: Only CBOD5 is measured, leaving non-biodegradable organic pollutants unaccounted for.

Risks: Non-biodegradable pollutants may contribute to long-term oxygen depletion in receiving waters.

Proposed Enhancement: Add COD testing to capture total oxygen demand, including contributions from non-biodegradable organic matter.

Benefits: COD testing provides a broader measure of the effluent's oxygen demand, helping to identify non-biodegradable organic pollutants and supporting a fuller understanding of effluent composition.

4.3.3 Enhanced TSS Analysis

Current Practice: TSS is measured as a bulk parameter without distinguishing between organic and inorganic components.

Risks: Lack of differentiation limits understanding of sediment sources and alum dosing efficiency.

Proposed Enhancement: Further analysis of TSS to separate organic vs. inorganic components.

Benefits: Identifying the composition of TSS can improve insights into sources of sediment and assess the effectiveness of alum dosing for removing particulate phosphorus.

4.3.4 Toxicity Testing

Current Practice: No toxicity testing is conducted to assess the combined effects of pollutants in effluent.

Risks: Synergistic impacts of multiple pollutants on aquatic organisms remain unassessed.

Proposed Enhancements: Conduct bioassays using fish or invertebrates to evaluate effluent toxicity during peak discharge periods.

Benefits: Periodic toxicity testing using standardized bioassays (e.g., fish or invertebrate toxicity tests), especially during high-discharge periods provides a direct assessment of the effluent's potential harm to aquatic organisms, allowing proactive management to reduce adverse ecological impacts.

4.4. Gaps: Summary of Recommendations

High-priority gaps, such as nutrient speciation, pathogen indicators, groundwater monitoring, emerging contaminants, and stricter limits address immediate environmental risks and regulatory demands. Medium-priority gaps provide valuable data on ecosystem health and long-term sustainability, while lower-priority gaps refine operational practices and optimize lagoon performance. Addressing these gaps strategically will ensure the Madoc Sewage Lagoon continues to protect sensitive ecosystems, meet community expectations, and comply with future regulatory standards.

Table 1: Recommended Water Quality Parameters for Monitoring

Parameter	Priority	Benefit
Soluble Reactive Phosphorus (SRP)	High	Early warning of bioavailable phosphorus contributing to eutrophication
Nitrate	High	Detects potential nutrient loading and oxygen demand
Dissolved Oxygen (DO)	High	Detects hypoxia; supports discharge timing decisions
E. coli	High	Assesses pathogen risks in effluent and receiving waters
Microplastics	Medium	Emerging concern in aquatic ecosystems and public health
Pharmaceuticals	Medium	Tracks compounds potentially affecting endocrine systems
Endocrine Disruptors	Medium	Helps evaluate risks to reproduction and development in aquatic life
Nitrite	Medium	Supplementary indicator of nitrogen transformation processes
Chlorophyll-a	Medium	Proxy for algal biomass; useful in tracking eutrophication
Chemical Oxygen Demand (COD)	Low	Identifies oxygen demand from organic and inorganic compounds
Enhanced TSS	Low	Tracks finer particulates not captured by standard TSS monitoring
Aluminum	Low	Indicators of sediment mobilization or leaching from soils
Iron	Low	Can influence aquatic toxicity and sediment interactions
Manganese	Low	Tracks redox conditions and possible infrastructure impacts

In addition to these recommended water quality parameters, PWQO Compliance, Ecological Monitoring, and Toxicity Testing should be implemented.

5. Climate Risk Analysis and Adaptive Management

Climate change is altering precipitation patterns, temperature regimes, and seasonal hydrology in eastern Ontario (See Appendix 3). For a seasonal-discharge lagoon like Madoc's, these changes affect treatment performance, discharge timing, and environmental impacts in receiving waters such as Moira Lake. This section summarizes the key risks and adaptive strategies.

5.1 Observed Climate Impacts on Lagoon Operations

5.1.1 Extreme Spring Inflows

Observed Patterns: Spring influent flows to the Madoc lagoon have periodically approached or exceeded the system's rated average daily flow capacity of 1,008 m³/day. Notably, peak flows in 2019 (1.07×) and 2021 (1.04×) exceeded this limit, consistent with regional projections of increased precipitation intensity during winter and early spring (OCWA Annual Reports, 2019 & 2021; see also Appendix A3.3.2). These exceedances are typically associated with short-duration, high-intensity storm events, which drive inflow and infiltration (I/I) through legacy infrastructure.

Risk Implication: Such events shorten the lagoon's hydraulic retention time from the design ~120 days to under 60 days, according to treatment design assumptions referenced in the Madoc Lagoon Climate Change Addendum (Appendix A2.3.1). Reduced retention time compromises BOD₅ and TSS removal performance and elevates the risk of discharge under hydrologically sub-optimal conditions.

The OCWA 2021 Annual Report notes:

“Spring influent flows reached an average of 1,048 m³/day over a 7-day period in April 2021, temporarily exceeding the system's rated capacity... retention time under these conditions is estimated to be approximately 50–55 days, well below the preferred operational threshold.” (OCWA, 2021 Annual Report, Section 3.2)”

These patterns are not isolated. Flow records from 3 of the last 7 years show spring influent levels exceeding 95% of rated capacity, validating the

projected I/I sensitivity under changing precipitation regimes (Appendix A3.3.2).

5.1.2 Misaligned Discharges

Observed Patterns: The Madoc lagoon operates on fixed seasonal discharge windows: April 1–May 20 (spring) and October 15–December 15 (fall), as stipulated in ECA 6702-BAGUX3. However, operational data from OCWA Annual Reports between 2018 and 2024 show that in some years, these windows have not aligned with optimal hydrological conditions in the receiving environment, particularly Deer Creek.

- In fall 2023, baseflows in Deer Creek were approximately 35% below the long-term October median, based on discharge data from the Water Survey of Canada station at Moira River near Foxboro (02HM007) and interpreted in OCWA's 2023 report (Appendix A2.3.4).
- In contrast, spring 2019 and 2021 discharges coincided with elevated creek flows, with daily rates above the Q80 percentile, leading to increased dilution potential but also heightened risk of plume mobilization and reduced contact time.

Risk Implication: When water levels are low, these imbalances make it harder for the river or lake to clean itself. When water levels are high, they change how nutrients move through the system. Fall discharges during drought-like conditions (e.g., 2020, 2023) coincide with impaired dilution, increasing the potential for phosphorus exceedances relative to the Provincial Water Quality Objective (PWQO) of 0.03 mg/L for total phosphorus in streams discharging to lakes (MECP, 1994).

Conversely, spring discharges during high-flow periods can result in peak daily flows 3.5–3.8× above the lagoon's average dry-weather discharge rate, as recorded during April 2019 and April 2021. These surges raise the likelihood of solids carryover, reduced phosphorus settling, and brief exceedances of final effluent TSS and TP targets—outcomes noted in the OCWA 2019 and 2021 Annual Reports.

These patterns support the need to consider hydrological flexibility within discharge planning.

5.1.3 Effluent Temperature and Pathogen Survival

Observed Patterns: Effluent temperature data from OCWA (2018–2024) indicate a gradual warming trend in both spring and fall discharge periods:

- Spring effluent temperatures increased from 9–10 °C (2018–2020) to 12–14 °C (2021–2023), particularly during late April to early May discharge weeks.
- Warmer autumns have also elevated fall discharge temperatures, with readings exceeding 13 °C as late as mid-November in 2021 and 2023.

This warming trend aligns with regional climate model projections showing a 1.5–2.5 °C increase in average air temperatures by the 2050s (Phase 2 Climate Addendum, Appendix A3.2).

Risk Implication: Elevated effluent temperatures carry multiple implications:

- Warmer water holds less dissolved oxygen, reducing the receiving water’s capacity to absorb additional biological loads. A 2–3% decrease in oxygen solubility is estimated for every 1 °C rise above baseline, increasing early-season oxygen demand in Moira Lake (Appendix A3.3.1).
- Warmer effluent extends the viability period of pathogens such as *E. coli*, *Giardia*, and *Cryptosporidium*, especially in the absence of tertiary disinfection systems. Studies show bacterial die-off rates are temperature-dependent, with lower inactivation at higher temperatures (e.g., Sinton et al., 2002; Appendix A3.3.1).

Supporting this, OCWA’s 2023 report states:

“In 2021 and 2023, E. coli concentrations measured near the end of the discharge period (November 30–December 7) were above 100 CFU/100 mL despite upstream values being <10 CFU/100 mL. This suggests reduced die-off and potential persistence in the water column under elevated effluent temperatures late in the season.” (OCWA Annual Report, 2023; Appendix A2.3.3)

These findings support the need to reassess discharge timing and consider thermal mitigation or polishing technologies for elevated-risk periods.

5.1.4 Hydrologic Stressors: Dilution Capacity and Stratification Risk

Observed Patterns: Quinte Conservation declared Level II or III droughts in 2012, 2016, and 2023 (Madoc Lagoon Climate Change Technical Memo, 2023). Verified streamflow records from WSC Station 02HL001 (Moira River at Foxboro) show:

- 2012: Average summer flow = 7.21 m³/s → ~65% of long-term mean
- 2016: 4.31 m³/s → ~39%
- 2023: 5.39 m³/s → ~48%

These low baseflow conditions coincided with seasonal discharge periods from the Madoc Lagoon.

Risk Implication: Reduced streamflow lowers dilution ratios from >10:1 (typical) to as low as 3:1, increasing the risk of nutrient exceedances even when effluent meets regulatory limits. These conditions also elevate concentrations of phosphorus and pathogens in receiving waters during discharge events, especially in fall.

Clarification: Low-flow conditions reduce water turnover and mixing in Moira Lake, increasing the likelihood of thermal stratification—where warmer surface waters are separated from cooler, denser bottom layers. This stratification limits oxygen transfer to bottom waters, and in the absence of mixing, dissolved oxygen is steadily consumed by sediment microbial activity and respiration. Over time, this leads to hypoxic (< 2 mg/L DO) or anoxic conditions.

5.1.5 Ecological Consequences: Species Shifts in Moira Lake

Risk Implication: Hypoxic conditions favour tolerant or invasive species such as cyanobacteria and zebra mussels, at the expense of native aquatic species. Climate-driven changes to discharge timing and nutrient loads may amplify these ecosystem shifts by contributing to oxygen stress during already vulnerable periods. These changes pose long-term risks to aquatic biodiversity, fisheries, and recreational use of Moira Lake.

5.2 Confirmation of Climate Impacts on Madoc Lagoon (2018–2024)

Comparing climate predictions with seven years of lagoon data shows that some of the expected climate impacts are already happening (Table 2).

This cross-reference confirms that several modeled climate impacts, including extreme rainfall events, warmer seasonal conditions, altered ice cover, and drought-related low flows, are already detectable in Madoc Lagoon’s operational record.

- High spring influent volumes in multiple years support the system’s documented I/I vulnerability (*Annual Report, 2023*).
- Rising effluent temperatures and low autumn flows illustrate elevated risk for reduced oxygen solubility and diminished nutrient assimilation in Moira Lake.
- The persistence of total phosphorus (TP) exceedances in receiving waters during discharge windows suggests that climate-related stressors are intensifying the impacts of system limitations, elevating eutrophication risk under both high-flow (e.g., solids carryover) and low-flow (e.g., low dilution) scenarios.

Table 2: Confirmation of Climate Impacts on Madoc Lagoon

Risk Driver	Observed Metric (2018–2024)	Trend	Climate Link	Source
Extreme rainfall & I/I	Spring influent up to 1.07× rated capacity (2019)	3 of 7 years > 0.95×	Greater Winter/Spring precipitation intensity	<i>Madoc Sewage Lagoon Annual Report, 2023</i>
Late ice cover	2021 spring discharge occurred under partial ice	1 clear example	Warmer winters with variable freeze–thaw patterns	<i>Operator Log Notes (Madoc Annual Report, 2021)</i>
Effluent temperature	May/Nov discharges 7–15 °C	+0.5–1 °C over period	Greater seasonal air temperature	<i>Madoc Sewage Lagoon Annual Report, 2023</i>
Autumn drought	Low-flow November discharges (2020, 2023)	2 years	Greater drought frequency	<i>Climate Change Technical Memo (2023); WSC Station 02HL001 Data</i>
Downstream PWQO exceedance (TP)	Multiple exceedances during discharge periods	Persistent	Reduced dilution, pulse loading	<i>Madoc Sewage Lagoon Annual Report, 2023; MECP PWQO Guidelines</i>

5.3 Future Scenarios Under Climate Change

This section supports long-term planning by illustrating how projected climate changes could affect the lagoon’s influence on Deer Creek and Moira Lake. While the 2024 Madoc Lagoon Master Plan outlines infrastructure needs, this section complements that work by modeling how future conditions—such as heavier spring inflows, warmer effluent, and reduced autumn streamflow—could impact discharge timing, compliance, and downstream water quality. Using scenario modeling and regional climate data, it presents three likely futures for the 2050s to guide adaptive planning that protects receiving waters through smarter scheduling, monitoring, and risk mitigation.

Table 3: Forward-Looking Climate Scenarios and Their Impacts on Lagoon Performance

	2050s Wet-Year	2050s Dry-Year	Temperature Effects
Key Climate Driver	+20% precipitation	1 in 3 autumns drought	14–18°C effluent
Operational Impact	+15–25% influent	Low dilution	+25–40% pathogen survival
Environmental Risk	More discharge volume	Higher PWQO exceedance risk	Lower DO solubility

5.3.1 2050s Wet-Year Scenario

A projected +20% increase in winter/spring precipitation (Appendix A) could elevate spring influent volumes by 15–25%, primarily due to increased I/I from saturated soils and more frequent short-duration, high-intensity storms. This would shorten hydraulic retention time and potentially necessitate:

- Two to three additional weeks of spring discharge, or
- Expansion of lagoon storage capacity to delay discharge until optimal receiving conditions are met. *Source: Madoc Phase 2 Master Plan, 2024; Climate Change Technical Memo (2023)*

5.3.2. 2050s Dry-Year Scenario

Under a drier seasonal regime, autumn droughts are projected to occur in 1 in every 3 fall seasons, based on regional climate trend analysis. This increases the likelihood that lagoon discharges would coincide with Level I or Level II low water conditions, reducing flow in Deer Creek and Moira Lake. Consequences include:

- Reduced dilution capacity, elevating downstream concentrations of total phosphorus, ammonia, and bacteria;
- Greater risk of PWQO exceedances, particularly during the second half of the discharge window when baseflows are lowest.

Source: Quinte Conservation drought archives; WSC hydrometric data (Station 02HL001); Phase 2 Master Plan discharge modeling (2023)

5.3.3. Temperature Effects on Discharge Quality

Ongoing warming trends are expected to raise mean effluent temperatures to 14–18 °C during both spring and fall discharge windows. Higher effluent temperatures have the following implications:

- Pathogen survival (e.g., E. coli, Giardia, Cryptosporidium) could increase by 25–40%, particularly in cooler surface waters of the receiving environment;
- Oxygen solubility in Moira Lake would decline by ~2–3%, further stressing aquatic ecosystems, especially when coupled with low flow and nutrient enrichment.

Source: MECP water quality criteria; Phase 2 Master Plan; Literature on pathogen die-off and DO–temperature dynamics

5.4 Recommended Climate Adaptation Measures for Lagoon Operations

The 2024 Climate Change Technical Memorandum for the Madoc Lagoon highlights key climate-related risks, including fluctuating inflows, warmer effluent, and lower streamflow for dilution. This section builds on those findings with practical

operational and monitoring strategies to help the lagoon adapt. These recommendations go beyond infrastructure upgrades by focusing on flexible day-to-day operations and lessons learned from 2018–2024. The goal is to maintain compliance and protect Moira Lake as conditions become warmer and more variable.

5.4.1. Discharge Management

- Introduce flow- and temperature-based triggers to supplement the fixed ECA discharge windows, aligning with MECP adaptive management principles.
- Integrate Quinte Conservation’s real-time drought monitoring (e.g., Level I–III alerts) and WSC streamflow gauges (e.g., Station 02HL001) to defer discharges during low-flow periods.
- Rationale: Late-fall discharges in 2020 and 2023 occurred during declared drought conditions (Level I in 2020, Level II in 2023), reducing dilution capacity and increasing downstream water quality risks (Madoc Annual Reports, 2021–2023; Quinte Conservation Drought Status Reports; Appendix A3.3.3).

5.4.2. Influent Control

- Prioritize high-risk sewer-sheds identified in the Phase 1 & 2 Master Plan hydraulic models for CCTV inspections and infrastructure upgrades.
- Use OCWA influent records to flag years (e.g., 2019, 2021) where spring flows exceeded 95–107% of design capacity, confirming I/I vulnerabilities (OCWA Annual Reports; Appendix A2.3.1).
- Outcome: Reduces wet-weather surges that compress retention time, degrade treatment, and increase solids carryover risk.

5.4.3. Pathogen & Temperature Mitigation

- Employ in-cell cooling strategies (e.g., surface mixers or floating covers) to moderate effluent temperature in warmer seasons.
- Evaluate tertiary treatment upgrades such as UV disinfection or constructed wetlands for high-risk discharges during elevated effluent temperatures.

- Evidence: Effluent temperatures reached 12–14 °C in 2021–2023, with late-cycle *E. coli* counts exceeding 100 CFU/100 mL, suggesting reduced bacterial die-off and increased recreational water risks (Madoc Lagoon Annual Report, 2023; Appendix A3.3.1).

5.4.4. Monitoring Enhancements

To better detect climate-related impacts and guide adaptive operations, the following enhancements to the current monitoring program are recommended:

- Expand effluent monitoring beyond current ECA parameters (CBOD₅, TSS, TP, pH, and temperature) to include:
 - Soluble reactive phosphorus (SRP)
 - Nitrate
 - Dissolved oxygen (preferably continuous)
 - *E. coli*
 - Ammonia
- Goal: Enable earlier detection of water quality risks linked to climate change (e.g., stratification, hypoxia, nutrient accumulation) and validate environmental performance in real time.

See Section 4. Gaps in the Current Testing Regime for further discussion.

5.4.5. Storage Planning

Objective: Increase lagoon system resilience by enabling greater control over discharge timing, specifically to avoid late-season discharges during dry or ecologically sensitive periods.

- Assess the feasibility of modest storage expansion measures (e.g., berm raising, passive holding cells) that would improve capacity to retain peak spring flows without triggering additional discharges.
- Context: In 2019 and 2021, spring influent volumes reached 3.5–3.8× average dry-weather flows, straining lagoon capacity and risking reduced treatment efficiency (Appendix A2.3.1; A3.3.2).

- **Rationale:** By temporarily storing high spring flows, the system can defer or avoid discharges during low-flow periods in the fall, when dilution is limited and Moira Lake is more vulnerable to eutrophication and hypoxia.
- **Key Principle:** Additional storage is proposed not to increase discharge frequency, but to provide operational flexibility to reduce discharge impacts under variable and extreme climate conditions.

5.5 Summary of Key Climate Change Implications

Drawing on the *Madoc Lagoon Master Plan*, the *Climate Change Technical Memorandum*, OCWA performance data (2018–2024), and peer-reviewed research, several climate-driven risks emerge as having the greatest potential to affect lagoon performance and downstream water quality. Full technical analysis is provided in Appendix 2.

- **Increased Inflow & Infiltration (I/I):** Heavy rainfall events—projected to become more intense in Eastern Ontario—are already driving lagoon influent volumes above the average daily design capacity. Historical OCWA data show peak influent flows reaching up to 4× typical dry-weather flows during extreme I/I events, particularly in older sewer sheds (Appendix A2.3.1; Appendix A3.3.2). These surges shorten retention time and increase the risk of solids breakthrough and nutrient exceedance under sub-optimal discharge conditions.
- **Reduced Dilution Capacity During Drought:** Declared drought years (e.g., 2012, 2016, 2021, 2023) in the Moira watershed correspond to documented reductions in Deer Creek baseflow to as low as 39–48% of the long-term mean (WSC Station 02HL001; Appendix A2.3.4). These diminished flows reduce the creek’s assimilative capacity and increase the likelihood of total phosphorus and ammonia concentrations exceeding PWQO limits—even when effluent remains compliant.
- **Warmer Effluent Temperatures:** Warmer seasonal air temperatures and shorter ice-cover periods are driving effluent temperatures in May and November to 12–14 °C, up from 9–10 °C in 2018–2020 (OCWA reports; Appendix A2.3.3). This reduces oxygen solubility in Moira Lake, elevates early-season oxygen demand, and accelerates microbial activity, which may hasten sludge accumulation and degrade secondary treatment performance.

- **Internal Nutrient Loading in Moira Lake:** Extended summer warming and low-flow conditions increase the frequency of bottom-water hypoxia (<2 mg/L DO) in Moira Lake. These conditions promote phosphorus release from sediments, sustaining algal blooms even in the absence of external inputs (Appendix A3.3.3).
- **Pathogen Survival in Receiving Waters:** Elevated effluent temperatures in shoulder seasons can prolong the survival of pathogens including *E. coli*, *Enterococcus*, *Giardia*, and *Cryptosporidium*, raising public health risks downstream (Appendix A2.3.3; Appendix A3.3.1). In 2021 and 2023, *E. coli* concentrations >100 CFU/100 mL were recorded in late-season discharge samples (Madoc Lagoon Annual Report, 2023).

These risks underscore the need for adaptive lagoon management, including:

- Flexible discharge protocols,
- Targeted I/I reduction,
- Enhanced seasonal effluent monitoring, and
- Proactive contingency planning for hydrologic extremes.

5.6 Strategic Adaptation Actions

To address the climate-driven risks outlined in Sections 5.1–5.5 and documented in Appendices 2 and 3, a set of adaptive strategies is recommended to improve the lagoon’s resilience under projected Moira watershed climate conditions. While the Master Plan addresses long-term infrastructure needs, these recommendations focus on operational flexibility, targeted monitoring, and low-cost risk mitigation—particularly under conditions where temperature, flow, or pathogen behaviour diverges from historic norms.

- **Adaptive Discharge Protocols:** Implement real-time streamflow, temperature, and rainfall-based discharge decision-making, rather than relying solely on fixed ECA windows. This allows operators to defer or advance discharges to avoid low-flow, high-risk periods. This approach is consistent with MECP’s adaptive management principles and regional best practices (e.g., Alberta Environment & Parks *Lagoon Operations Manual*, 2018) (Appendix A2.6).

- **Tertiary Treatment Upgrades:** Add polishing steps—such as constructed wetlands or UV disinfection—to reduce nutrients and pathogen loads during shoulder-season discharges when higher effluent temperatures may reduce natural attenuation (Appendix A3.3.1). These technologies are supported in recent MECP-funded lagoon reviews and help future-proof the system.
- **Enhanced Climate-Sensitive Monitoring:** Expand effluent and receiving-water sampling to include:
 - Effluent temperature, soluble reactive phosphorus (SRP), and pathogen indicators (e.g., *E. coli*, *Giardia*)
 - Continuous dissolved oxygen and ammonia levels during discharge periods
This will improve the detection of climate-amplified water quality risks (Appendix A2.3.3; Appendix A3.3.1).
- **I/I Control and Sewer System Resilience:** Prioritize high-I/I sewer-sheds identified through Phase 1 and 2 sewer modeling. Implement cost-effective lining, repair, or diversion projects to reduce inflow surges during extreme rainfall—particularly in aging infrastructure (Appendix A2.3.1). This protects lagoon retention time and compliance margins.
- **Public Risk Communication:** Collaborate with Quinte Conservation and the local Health Unit to develop public alerts during high-risk discharge periods—especially when algal blooms or elevated pathogen counts are likely. This is consistent with Ontario’s *Blue-Green Algae Risk Communication Protocol* (Appendix A3.3.3).
- **Drought-Responsive Discharge Scheduling:** Embed Quinte Conservation’s drought monitoring data (e.g., Level I–III declarations) into spring and fall discharge planning. Avoiding discharges during Level II/III periods will reduce nutrient concentrations and protect Moira Lake’s assimilative capacity during sensitive low-flow periods (Appendix A3.3.3).

These climate-adaptive measures emphasize flexibility, early warning, and public health safeguards. When applied alongside the Master Plan’s infrastructure upgrades, they can ensure lagoon performance remains compliant, resilient, and environmentally protective through mid-century and beyond.

5.7 Conclusion: Ensuring Long-Term Resilience

A synthesis of 2018–2024 OCWA operational data, climate projections from the Madoc Lagoon Phase 2 Master Plan, and peer-reviewed scientific literature confirms that several climate-related risks are no longer hypothetical: they are already influencing lagoon operations and receiving-water quality.

Key indicators include:

- Peak spring inflows that have, in multiple years, approached or exceeded the lagoon’s rated capacity, reflecting increased inflow and infiltration (I/I) during extreme rainfall events.
- Low-flow autumn discharges in drought years (e.g., 2020, 2023), reducing the dilution capacity of Deer Creek and elevating the risk of downstream nutrient exceedance.
- Steadily rising effluent temperatures in shoulder seasons, aligning with regional warming trends and intensifying stress on dissolved oxygen dynamics and pathogen persistence.

These observed patterns correlate closely with modeled wet-year, dry-year, and warming scenarios, reinforcing the validity of projected climate pathways and their relevance to near-term infrastructure and compliance planning.

Given this convergence of modeled and real-world evidence, a transition is warranted—from fixed-window discharge scheduling and static operational rules to adaptive, data-informed lagoon management. This shift will require:

- Real-time use of streamflow, temperature, and precipitation data.
- Targeted I/I controls and sewer system upgrades.
- Monitoring and mitigation measures for thermal stress, pathogens, and nutrient impacts.

By embedding these strategies—alongside public risk communication, enhanced effluent monitoring, and drought-responsive planning—the lagoon system can

remain compliant, resilient, and environmentally protective under increasing climate variability.

This integrated adaptation approach will help safeguard Moira Lake’s ecological health, mitigate eutrophication and public health risks, and ensure the lagoon system remains fit-for-purpose through 2050 and beyond.

6. Observations of Lake Residents

On a recent survey of Moira Lake residents environmental concerns and water quality monitoring were chosen by 48% of respondents as the number one area having a positive impact moving forward (Fall 2024 Moira Lake Stakeholder Survey).

Even though empirical data indicate that, for the parameters tested for, the Madoc Sewage Lagoon is currently meeting provincial regulatory levels, local residents often present a different view:

“When I saw the stuff floating around my dock and boat lift it made me very sad and alarmed to see what was happening. To me there was no doubt as to where this filth was coming from.” **James Rainie, 27-year resident of Moira Lake.**

“Growing up on Moira Lake it has been difficult to see the water quality change. From what I have seen, the zebra mussels creating more clarity combined with nutrient from the sewage lagoon have created weed growth in areas and depths I have previously never seen.” **Michael Steele, Lifetime resident of Moira Lake.**

And from feedback in the Fall 2024 Moira Lake Stakeholder Survey:

“Moira lake is a relatively shallow, eutrophic body of water whose quality and clarity are very sensitive to even the smallest of human generated changes. Therefore, the Moira Lake Property Owners Association must be relentless in its efforts to ensure that all property owners, the municipality, and all other stakeholders are all doing their utmost to protect the lake waters, including waters entering and leaving the two basins.

“I would like to see the flushing of the lagoon into the lake permanently halted.”

“Water quality must be improved, ... no more flushing the lagoon into the lake.”

The disconnect between residents’ real-life observations and testing data needs to be addressed. It is possible that an explanation for the discrepancy may be revealed with more comprehensive testing. At a minimum improved communication is required.

7. Summary and Recommendations

The Madoc Sewage Lagoon is a vital wastewater management facility for the Municipality of Centre Hastings, protecting downstream ecosystems like Deer Creek and Moira Lake. While the lagoon currently meets Ontario’s ECA regulatory standards, gaps in monitoring and operational practices highlight opportunities for improvement to address environmental risks, align with emerging regulatory standards, and respond to community concerns.

7.1 Key Findings

1. Regulatory Compliance:

- The lagoon complies with Environmental Compliance Approval (ECA) standards for Carbonaceous Biochemical Oxygen Demand (CBOD5), Total Suspended Solids (TSS), and total phosphorus.
- Despite ECA regulatory compliance, downstream phosphorus levels frequently exceed PWQOs, contributing to nutrient enrichment and increased eutrophication risk in Deer Creek and Moira Lake. Occasional exceedances of CBOD5 PWQOs downstream suggest localized impacts on dissolved oxygen levels, particularly during high-flow spring discharges.

2. Environmental Risks:

- Spikes in CBOD5, TSS, and phosphorus observed in 2023 emphasize the importance of monitoring and mitigating factors contributing to these anomalies.
- Climate change exacerbates challenges such as increased nutrient loading, reduced dilution capacity, and elevated effluent temperatures, requiring adaptation measures.

3. Community Concerns:

- Residents report visible environmental degradation in Moira Lake, such as algal blooms and sedimentation, which they attribute to lagoon discharges. These concerns underscore the need for enhanced transparency, monitoring, and communication.

4. Testing Gaps:

- The existing testing program omits several critical parameters, limiting the ability to address long-term ecological risks and prepare for future regulations. Key gaps include:
 - Nutrient Speciation: Absence of testing for bioavailable phosphorus (SRP) and nitrogen species, which are critical for understanding eutrophication dynamics.
 - Pathogen Indicators: Lack of microbial testing, such as E. coli and Enterococci, to ensure recreational water safety.
 - Groundwater Monitoring: No monitoring of potential seepage impacts on aquifers.
 - Emerging Contaminants: Absence of testing for pharmaceuticals, microplastics, and endocrine disruptors, which are increasingly recognized as ecological threats.

7.2 Recommendations

To address current monitoring gaps, projected climate impacts, and community concerns, the following actions are recommended.

7.2.1 High-Priority Actions

1. Expand Nutrient Monitoring and Control

- Add soluble reactive phosphorus (SRP), nitrate, nitrite, and ammonia testing.
- Focus on reducing eutrophication risk and addressing frequent exceedances of PWQOs (0.03 mg/L for rivers; 0.02 mg/L for lakes).

2. Reintroduce Pathogen Testing

- Monitor E. coli and Enterococci during discharge periods to assess public health risks near water-contact areas.
- 3. Implement Flow- and Temperature-Triggered Discharge Controls**
 - Supplement fixed ECA windows with adaptive criteria using WSC gauges and Quinte Conservation drought alerts.
 - 4. Target Inflow & Infiltration (I/I) Hotspots**
 - Use OCWA inflow data to identify years with >95–107% of design capacity (e.g., 2019, 2021) and prioritize mitigation accordingly.
 - 5. Monitor Dissolved Oxygen (DO)**
 - Add spot and continuous DO monitoring at effluent and downstream locations to detect hypoxia and support adaptive management.
 - 6. Adopt More Stringent Testing Standards**
 - Report against PWQO thresholds and explore compliance with emerging regulatory frameworks in other jurisdictions.

7.2.2 Medium-Priority Actions

- 7. Pilot Emerging Contaminant Testing**
 - Conduct pilot-scale testing for pharmaceuticals, endocrine disruptors, and microplastics.
- 8. Implement Ecological Monitoring**
 - Track biological indicators (benthic invertebrates, algal biomass, fish health) to detect long-term impacts on aquatic ecosystems.
- 9. Monitor Chlorophyll-a**
 - Use as an early indicator of nutrient enrichment and algal bloom risk.
- 10. Manage Effluent Temperature and Pathogen Risk**
 - Monitor effluent temperature; evaluate shading/mixing or tertiary treatment during warm periods.
- 11. Establish Groundwater Monitoring**
 - Add semi-annual well sampling to detect potential subsurface leakage.

12. Evaluate Incremental Storage Options

- Assess berm raising or passive storage to reduce reliance on fall discharges during drought.

7.2.3 Lower-Priority Actions

13. Expand Metals Monitoring

- Periodically test for aluminum, iron, and manganese in effluent and sediments.

14. Include Chemical Oxygen Demand (COD)

- Track oxygen demand from non-biodegradable organics.

15. Enhance Total Suspended Solids (TSS) Characterization

- Differentiate between organic and inorganic TSS fractions to inform treatment adjustments.

16. Introduce Toxicity Testing

- Conduct periodic bioassays to assess combined pollutant effects on aquatic life.

7.2.4 Community Engagement

17. Strengthen Public Communication and Trust

- Share expanded monitoring results in accessible formats and host public info sessions tied to discharge periods or major changes.

18. Address Environmental and Health Concerns

- Create a public-facing summary of lagoon performance and risks, including disinfection practices, water quality, and climate resilience.

19. Encourage Stakeholder Participation

- Involve residents, conservation authorities, and Indigenous communities in setting water quality priorities and reviewing results.

8. Conclusion

This report builds upon the infrastructure-focused strategies outlined in the 2024 Madoc Lagoon Master Plan and its Climate Change Technical Memorandum by providing a complementary operational lens—one that prioritizes water quality outcomes in Moira Lake and Deer Creek.

While the Master Plan outlines long-term capital needs for infrastructure resiliency, this assessment focuses on near-term, adaptive actions to address both observed performance challenges and emerging climate risks. These include rising effluent temperatures, shifting hydrology, reduced dilution capacity, and ecological stress in receiving waters.

Historical analysis from 2018–2024 confirms that climate-sensitive impacts—such as high influent volumes, warm-season discharges, and reduced fall baseflows—are already affecting lagoon performance and downstream water quality. Although the lagoon remains within regulatory discharge windows and meets ECA limits for key parameters, it continues to contribute to nutrient loading and periodic PWQO exceedances, particularly for phosphorus.

To address these vulnerabilities, this report recommends a prioritized package of operational, monitoring, and engagement measures. High-priority actions include nutrient speciation (SRP, nitrate, nitrite, ammonia), reintroduction of pathogen testing, adaptive discharge scheduling, DO monitoring, and more rigorous alignment with PWQOs. Medium- and low-priority measures expand surveillance to emerging contaminants, ecological indicators, and sediment-related risks.

Crucially, this report also responds to rising public concern about environmental degradation in Moira Lake. By improving transparency, expanding communication efforts, and involving community stakeholders in water quality monitoring and planning, the Municipality can strengthen public trust and build a shared foundation for long-term watershed stewardship.

Together, these recommendations aim to ensure that the Madoc Lagoon is not only compliant, but also ecologically responsible and climate-resilient—protecting public health, aquatic ecosystems, and community values for years to come.

9. Acknowledgments

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Questions or comments regarding this report should be addressed to Doug McCarthy (President and Lake Steward, MLPOA) at moira.lake.poa@gmail.com.

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Appendix 1: Examples of Stricter Performance Objectives

This Appendix provides examples of performance objectives for CBOD5, Total Suspended Solids (TSS), and phosphorus from other jurisdictions, demonstrating different approaches to these key wastewater metrics. It also includes an overview of the increasing concern over emerging contaminants.

1. CBOD5 Standards

- **Ontario (Madoc Lagoon):** The regulatory limit is 30 mg/L, with a performance objective of 25 mg/L.
- **British Columbia, Canada:** The British Columbia Ministry of Environment sets CBOD5 standards for sensitive receiving waters, with site-specific permits often targeting limits of 15-20 mg/L in high-sensitivity areas (British Columbia Ministry of Environment, *Municipal Wastewater Regulation*, 2014).
- **United States (EPA):** The U.S. EPA's National Pollutant Discharge Elimination System (NPDES) program enforces a CBOD5 standard of 25 mg/L for secondary treatment but often applies stricter limits (10-15 mg/L) for discharges into critical habitats or sensitive water bodies (U.S. Environmental Protection Agency, *NPDES Permit Writers' Manual*, 2017).
- **European Union:** The EU Urban Waste Water Treatment Directive specifies a CBOD5 standard of 25 mg/L, with reductions to 15 mg/L for discharges into sensitive waters, aligning with the EU's Water Framework Directive for enhanced ecological protection (European Commission, *Council Directive 91/271/EEC on Urban Waste Water Treatment*, 1991).

2. Total Suspended Solids (TSS) Standards

- **Ontario (Madoc Lagoon):** The TSS limit is generally set at 30 mg/L, with a performance objective at 25 mg/L.
- **Quebec, Canada:** The Quebec Ministry of Environment enforces TSS standards between 15-25 mg/L for facilities discharging into sensitive areas, particularly near fish habitats (Ministère de l'Environnement et de la Lutte contre les changements climatiques, *Règlement sur les effluents d'eaux usées municipales*, 2019).

- **California, USA:** The California Water Resources Control Boards often enforce TSS limits as low as 10 mg/L, especially in coastal and recreational areas where sediment control is crucial (California State Water Resources Control Board, *California Ocean Plan*, 2019).
- **Australia (Victoria):** EPA Victoria mandates TSS levels below 20 mg/L in many scenarios, further reducing to 10-15 mg/L when effluent is discharged near sensitive ecosystems (EPA Victoria, *State Environment Protection Policy (Waters)*, 2018).

3. Phosphorus Standards

- **Ontario (Madoc Lagoon):** The current phosphorus limit is 0.5 mg/L, with a performance objective of 0.3 mg/L aimed at reducing eutrophication in downstream water bodies.
- **Alberta, Canada:** Alberta Environment and Parks imposes phosphorus limits as low as 0.1 mg/L in ecologically sensitive zones to protect downstream water quality (Alberta Environment and Parks, *Standards and Guidelines for Municipal Waterworks, Wastewater, and Storm Drainage Systems*, 2015).
- **Minnesota, USA:** The Minnesota Pollution Control Agency (MPCA) applies stringent phosphorus limits of 0.05-0.1 mg/L for discharges into lakes and slow-moving rivers with high eutrophication risks (Minnesota Pollution Control Agency, *Phosphorus Strategy for Minnesota's Surface Waters*, 2014).
- **European Union:** Many EU countries enforce phosphorus limits as low as 0.1 mg/L in highly protected water bodies, including Natura 2000 sites, which aim to preserve biodiversity across Europe (European Commission, *Water Framework Directive 2000/60/EC*, 2000).

4. Expanded Regulatory Trends for Emerging Contaminants

Emerging contaminants, such as pharmaceuticals, personal care products, microplastics, and industrial chemicals, are increasingly under scrutiny worldwide. Understanding regulatory trends is essential for preparing the Madoc Sewage Lagoon to meet future compliance requirements and align with best practices. Here's an expanded exploration of current and anticipated regulatory developments:

1. International Regulatory Developments

- **European Union (EU)**
 - **Water Framework Directive (WFD):** The EU has established mandatory monitoring programs for specific pharmaceuticals in surface and groundwater, recognizing their ecological risks. Substances like diclofenac (a common painkiller) and estrogenic hormones are now included on priority watch lists.
 - **Microplastics:** The EU is advancing restrictions on intentionally added microplastics (e.g., in cosmetics and detergents) while pushing for stringent monitoring of microplastic pollution in water bodies.
 - **PFAS (Per- and Polyfluoroalkyl Substances):** Comprehensive restrictions on PFAS are in progress under the EU's Chemical Strategy for Sustainability, with bans on specific uses in industrial processes.

- **United States**
 - **Environmental Protection Agency (EPA):** The EPA's Contaminant Candidate List (CCL) includes pharmaceuticals, hormones, and PFAS, which are considered for future drinking water and wastewater standards.
 - The EPA is also requiring monitoring of PFAS under the Unregulated Contaminant Monitoring Rule (UCMR 5), a precursor to potential regulatory limits.
 - **Microplastics Research:** Federal initiatives focus on quantifying microplastic pollution and evaluating their impacts on ecosystems and public health.
 - **Endocrine Disruptors Screening Program:** This program evaluates the environmental impacts of endocrine-disrupting compounds (EDCs), which are often found in wastewater effluent.

- **Australia**

- National guidance for wastewater reuse includes emerging contaminants such as hormones, pharmaceuticals, and personal care products. Treatment guidelines emphasize the importance of advanced oxidation processes and membrane filtration for removal.

2. Canadian Context

- **Federal Initiatives**

- **Microplastics Monitoring:** Environment and Climate Change Canada (ECCC) has identified microplastics as a significant concern, publishing research and guidance on their impacts on aquatic ecosystems. Microplastics were officially added to Canada's list of toxic substances in the Canadian Environmental Protection Act (CEPA) in 2021.
- **PFAS Regulation:** Canada is aligning its regulatory approaches with global trends by restricting specific PFAS compounds and exploring broader controls through CEPA.
- **Pharmaceuticals and Personal Care Products:** Health Canada and ECCC have conducted studies highlighting the prevalence of pharmaceuticals in surface water, flagging their potential environmental risks.

- **Provincial Frameworks**

- Ontario has yet to mandate monitoring of emerging contaminants in wastewater, but provincial frameworks are increasingly emphasizing source water protection and effluent quality.
- The Ministry of the Environment, Conservation and Parks (MECP) may introduce stricter discharge guidelines in response to community and environmental group advocacy, particularly for high-risk ecosystems like Moira Lake.

3. Anticipated Regulatory Shifts

- **Pharmaceutical and Hormonal Residues**
 - Anticipated regulations may require municipalities to monitor and mitigate pharmaceuticals like ibuprofen, estrogen, and antibiotics due to their cumulative ecological impacts.
 - Countries with proactive monitoring programs, such as Sweden, serve as models for integrating pharmaceutical thresholds into wastewater permits.
- **Microplastics**
 - Provinces may introduce monitoring requirements as part of a broader plastics management strategy, focusing on detecting and mitigating microplastics in effluent.
 - A national ban on certain microplastic-containing products could increase public demand for accountability in wastewater discharges.
- **Toxic Persistent Substances (PFAS)**
 - Given the global attention on PFAS, Canadian jurisdictions may soon adopt specific discharge limits for PFAS compounds. This aligns with recent moves by the United States and Europe to classify PFAS as hazardous.

Summary

Compared to standards in other jurisdictions, Madoc Lagoon's performance objectives align with average secondary treatment standards. However, jurisdictions with high-sensitivity ecosystems often impose stricter phosphorus limits (e.g., 0.1-0.2 mg/L) and, in some cases, more stringent CBOD5 limits (10-20 mg/L). Adopting similar standards could benefit Madoc by enhancing protection for local water bodies such as Deer Creek and Moira Lake against nutrient loading and organic pollution impacts.

Appendix 2 – Climate Change Impacts on Madoc Sewage Lagoon Performance

A2.1 Introduction

This appendix compiles climate-related research, data analysis, and operational cross-referencing conducted for the Madoc Sewage Lagoon between 2018 and 2024. It supports the main body’s Section 5 by providing detailed evidence, datasets, and expanded discussion.

The purpose is to:

- Demonstrate how modeled climate risks are already manifesting in operational data.
- Quantify linkages between climate variables and lagoon performance metrics.
- Provide a technical basis for the adaptive management recommendations in the main report.

A2.2 Climate Risk Pathways Identified

Purpose: This section outlines the main climate change mechanisms expected to affect the Madoc Lagoon’s ability to meet compliance and environmental performance objectives. It draws from the *Climate Change Technical Memorandum* (2024) and frames these mechanisms as “risk pathways” that connect climate drivers (e.g., temperature rise, altered precipitation) to operational or ecological effects.

Relevance: Understanding these pathways is essential for linking projected climate conditions to measurable changes in effluent quality, discharge timing, and downstream water quality. They form the foundation for the cross-referencing and scenario analysis that follow.

The *Climate Change Technical Memorandum* (2024) identifies five key pathways relevant to lagoon operations:

1. **Inflow/Infiltration (I/I) Sensitivity** – Increased winter/spring precipitation intensity driving peak influent flows near or above rated capacity.
2. **Fixed Discharge Timing vs. Variable Hydrology** – Mismatch between ECA windows and changing freeze–thaw cycles, drought timing, and storm frequency.
3. **Effluent Temperature Increases** – Higher seasonal air temperatures leading to warmer discharge, affecting oxygen solubility and pathogen survival.
4. **Reduced Dilution During Drought** – More frequent late-fall low flows in Deer Creek, reducing assimilative capacity.
5. **Nutrient and Pathogen Dynamics** – Risk of eutrophication and public health impacts during warm, low-flow discharges.

A2.3 Historical Performance Cross-Reference (2018–2024)

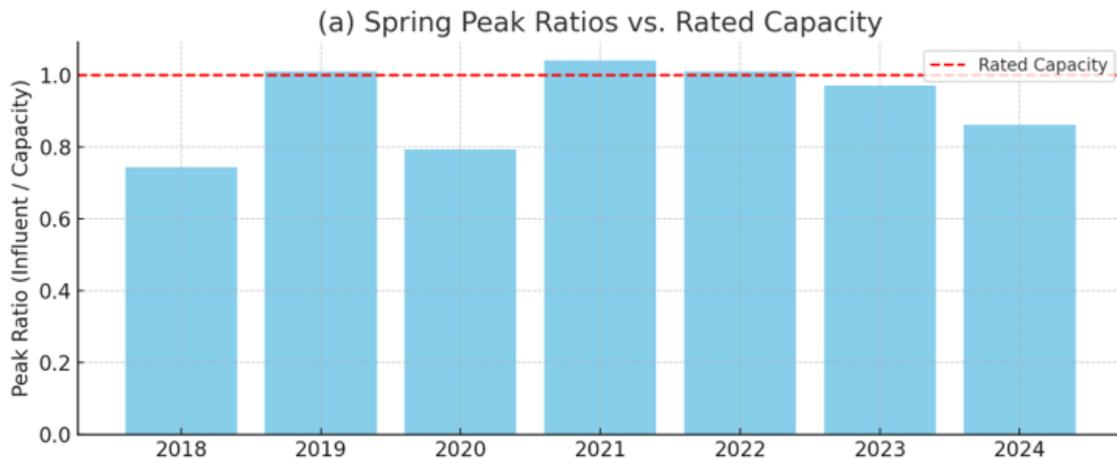
Purpose: This section compares observed lagoon performance data over seven years against the identified climate risk pathways. It uses OCWA annual reports and discharge logs to determine whether predicted climate effects are already detectable in hydraulic and effluent quality metrics.

Relevance: By aligning climate risks with historical operational records, we can determine the extent to which climate change is not only a future concern but also a present-day driver of performance variability. This evidence strengthens the case for proactive adaptation rather than reactive mitigation.

A2.3.1 Hydraulic Performance

- **Observed:** Rated Capacity: 1,008 m³/d. Spring peak inflow ratios ranged from 0.76–1.07, with exceedances in 2019 and 2021 linked to heavy rainfall events. Autumn storage levels occasionally forced discharges into drought conditions.
- **So What:** Flows near or above rated capacity shorten lagoon retention time, reducing treatment efficiency and increasing the risk that solids, nutrients, and pathogens are discharged at higher concentrations. Climate projections show these extreme inflow years becoming more frequent, meaning the lagoon may need greater storage flexibility or earlier seasonal discharges to maintain performance.

Figure A2.1 – Spring peak ratios vs. rated capacity, 2018–2024



A2.3.2 Discharge Timing

- **Observed:** All discharges occurred within ECA-approved windows. In 2021, the spring discharge occurred under partial ice cover. November discharges in 2020 and 2023 coincided with Level 1 drought advisories.
- **So What:** Even though regulatory timing was met, environmental conditions during discharge were sometimes suboptimal—ice cover can limit mixing and oxygen exchange, while drought conditions reduce dilution capacity. As climate shifts, these misalignments between fixed discharge windows and real-time hydrological conditions are expected to become more frequent, challenging both compliance and receiving-water health.

A2.3.3 Effluent Temperature

- **Observed:** Discharge temperatures ranged 7–15 °C, with warmer years (2019, 2023) exceeding 12 °C. These years also showed higher *E. coli* counts.
- **So What:** Warmer effluent holds less dissolved oxygen and can extend pathogen survival times, increasing ecological stress and public health risks. In a warming climate, discharge events will more often occur at temperatures

conducive to both lower oxygen solubility and higher pathogen persistence, making temperature management and disinfection more important.

A2.3.4 Effluent Quality vs. Receiving Water

- **Observed:** Effluent BOD₅, TSS, TP consistently below ECA limits. However, downstream phosphorus concentrations often exceeded the Provincial Water Quality Objective (PWQO) during discharge events.
- **So What:** Compliance with the ECA does not guarantee that receiving-water quality standards are met—especially during low-flow or warm-water conditions when assimilative capacity is reduced. This means lagoon discharges, even when “in compliance,” can still contribute to eutrophication and algal blooms in Moira Lake under climate-stressed conditions.

A2.4 Modeled Climate Projections

Purpose: This section summarizes projected changes in temperature, precipitation, and hydrology for the 2050s under high- and medium-emissions scenarios, with a focus on parameters directly relevant to lagoon operations. It draws from the Master Plan Phase 2 climate modelling outputs and the *Quinte Region Drought Plan*.

Relevance: Projections allow the municipality and operators to anticipate future stresses and integrate “climate readiness” into capital planning, operational scheduling, and permit renewal discussions. These forward-looking insights also provide context for risk prioritization in Section A.5.

A2.4.1 Hydrological Change

- By 2050s: +20% winter/spring precipitation in wet years.
- Increased likelihood of rapid snowmelt–rain events leading to high I/I surges.

A2.4.2 Thermal Change

- Seasonal mean air temperature increase: +2.5 to +4 °C.
- Projected effluent discharge temperatures: 14–18 °C in shoulder seasons.

A2.4.3 Low-Flow Conditions

- Frequency of autumn drought events projected to double by 2050s.
- Potential for 1 in 3 fall discharges to coincide with Level 1 drought.

A2.5 Scenario Analysis – Operational Implications

Purpose: This section models how different climate futures (wet years, late ice cover, warm effluent, autumn drought) could influence lagoon operations, compliance risk, and environmental impact. Each scenario is linked to a risk rating and potential adaptation need.

Relevance: Scenario analysis bridges the gap between raw climate projections and concrete operational decisions. By mapping climate events to their likely impacts on storage, treatment efficiency, and receiving-water quality, decision-makers can target investments and procedural changes where they will have the greatest benefit.

Table A2.1 – Scenario-based operational risk matrix

Scenario	Operational Impact	Risk Level	Adaptation Needs
Wet-year peak inflow	Reduced retention time, storage stress	High	I/I reduction, early spring discharge flexibility
Late ice cover	Reduced mixing during discharge	Medium	Flexible start date, ice monitoring
Warm effluent	DO depression, pathogen persistence	Medium–High	Shade/mixing, tertiary disinfection
Autumn drought	Reduced dilution, PWQO exceedance	High	Flow-triggered discharge deferral

A2.6 Recommended Climate Adaptations

Purpose: This section lists specific operational and infrastructure adaptations designed to reduce vulnerability to the risks identified in Sections A.2–A.5. These recommendations are informed by both historical data and modeled projections.

Relevance: Recommendations provide a direct pathway from climate impact recognition to actionable change. They are intended for integration into the lagoon’s ongoing optimization program, capital works planning, and regulatory engagement.

1. **Dynamic Discharge Management** – Use flow and temperature triggers in addition to ECA windows.
2. **I/I Mitigation** – Prioritise sewersheds with highest storm response.
3. **Thermal Control** – Reduce in-lagoon heating via shading/mixing.
4. **Pathogen Control** – Evaluate tertiary UV or filtration for warm-season discharges.
5. **Enhanced Monitoring** – Include temperature, ammonia, nitrate, and continuous DO.
6. **Capacity Planning** – Investigate incremental storage to manage peak inflows.

Appendix 3 – Ontario Climate Context for Lagoon Discharge and Moira Lake

A3.1 Introduction

This appendix summarizes observed and projected climate changes for Ontario and the Moira River watershed.

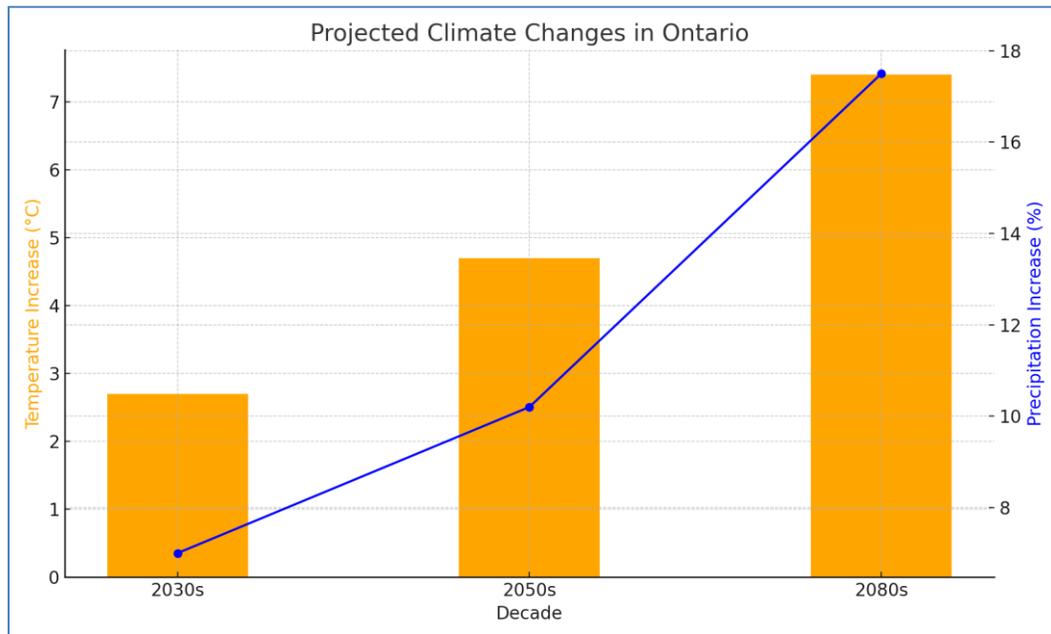
It provides the **regional context** for the climate risk pathways and local performance analysis presented in Appendix 2.

By connecting provincial-scale climate trends to lagoon operations, it shows that the Madoc Lagoon’s observed operational challenges are consistent with broader climatic shifts already underway in Ontario.

A3.2 Ontario Climate Projections

Ontario’s climate is projected to become significantly warmer and wetter (Ontario Climate Change Data Portal, 2024), with pronounced seasonal variability. Annual precipitation and average temperatures are both projected to increase (Sustainable Technologies Wiki, 2024) under all climate scenarios. These trends have direct implications for the performance and environmental impact of wastewater treatment lagoons.

Figure A3-1 – Projected temperature and precipitation changes in Ontario. Source: Ontario Climate Change Data Portal



A3.3 Observed Changes and Historical Data

Long-term climate monitoring in Ontario reveals several trends relevant to lagoon operations and downstream impacts.

A3.3.1 Temperature Trends

- Annual average temperature in Ontario has risen by approximately 1.5–1.7°C since 1950, with warming accelerating in recent decades.
- More days exceed 30 °C—up to 21 days, compared to a 30-year average of 13.5 days—indicating an increase in extreme heat events.
- Warming is more pronounced in winter and spring, leading to earlier snowmelt and an extended growing season.

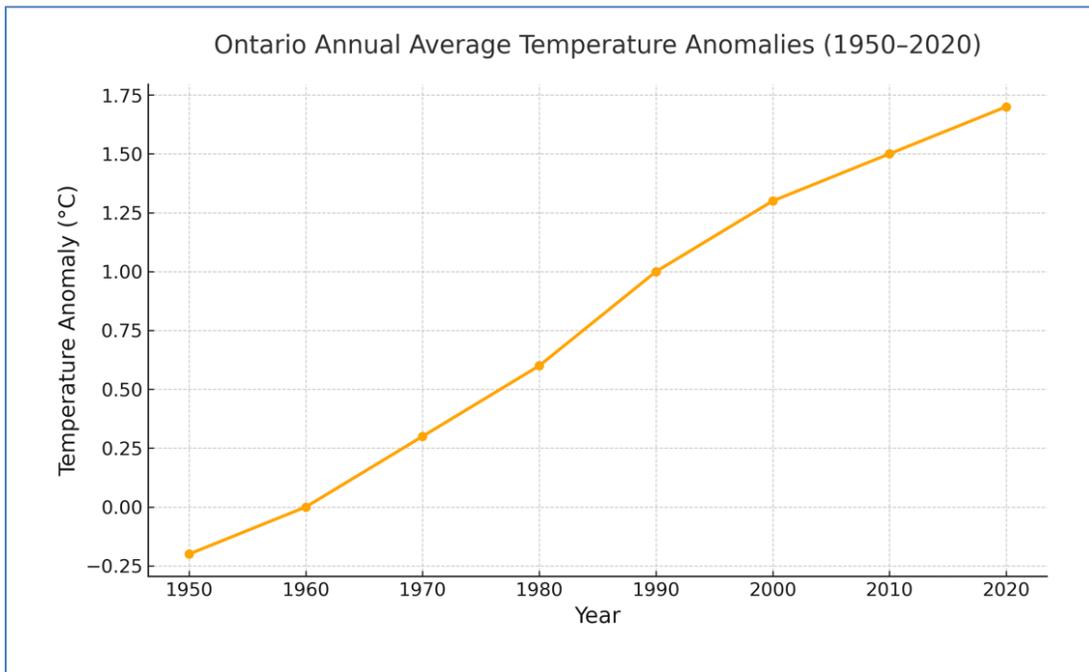
Implications:

- Earlier runoff timing may advance the spring phosphorus loading window in Moira Lake, heightening bloom risks (See *Appendix A2.3.4 – Effluent Quality vs. Receiving Water*).

- Warmer winters reduce ice cover duration on lagoons and lakes, altering oxygen dynamics and potentially affecting effluent stabilization in winter cells (See Appendix A.3.2 – Discharge Timing).
- Elevated summer temperatures raise effluent temperatures, potentially increasing pathogen viability and phosphorus bioavailability (See Appendix A2.3.3 – Effluent Temperature).

Figure A3-2 – Ontario Annual Average Temperature Anomalies (1950–2020).

Source: ECCC CANGRD dataset



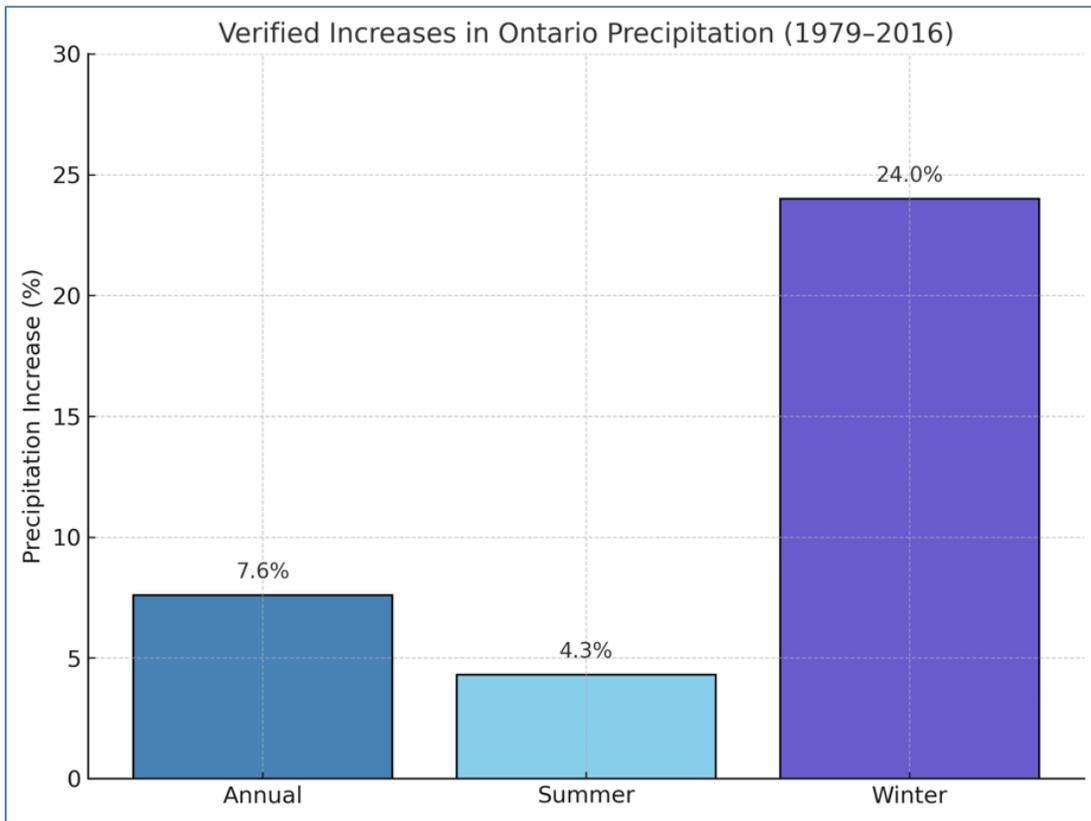
A3.3.2 Precipitation Patterns

- Between 1970 and 2020, annual precipitation increased by approximately **7.6%** in Ontario.
- Short-duration, high-intensity storms are more frequent, as indicated by shifting IDF curves.
- Much of southern Ontario, including Hastings County, has experienced notable winter precipitation increases.

Implications:

- Increased Inflow & Infiltration (I/I) within collection systems, especially in older or undersized infrastructure (See *Appendix A2.3.1 – Hydraulic Performance*).
- Overland flow and rapid catchment saturation can cause unexpected lagoon volume surges, overwhelming cell storage and treatment retention time (See *Appendix A2.3.1 – Hydraulic Performance*).

Figure A3-3 – Verified increases in Ontario precipitation (1979–2016). Source: York University; ECCC; MDPI study



A3.3.3 Low Streamflow and Drought Conditions

- Quinte Conservation declared drought conditions in multiple recent years (2016, 2023), including Level II and Level III advisories.

- ECCC streamflow records for the Moira River near Foxboro (Station 02HL001) show high variability but no clear long-term downward trend in average summer flows (2000–2023).
- More than half of the years since 2001 experienced some level of low-water conditions.

Implications:

- In drought years, dilution capacity downstream of the lagoons may be reduced, limiting assimilative capacity even when effluent meets ECA limits (See *Appendix A2.3.4 – Effluent Quality vs. Receiving Water*).
- Prolonged dry conditions can promote thermal stratification and hypoxia, potentially releasing phosphorus from sediments (See *Appendix A2.3.4 – Effluent Quality vs. Receiving Water*).
- These effects are episodic, emphasizing the need for adaptive lagoon management during drought periods (See *Appendix A2.6 – Recommended Climate Adaptations*).

A3.3.4 Storm Events and Wind Disturbance

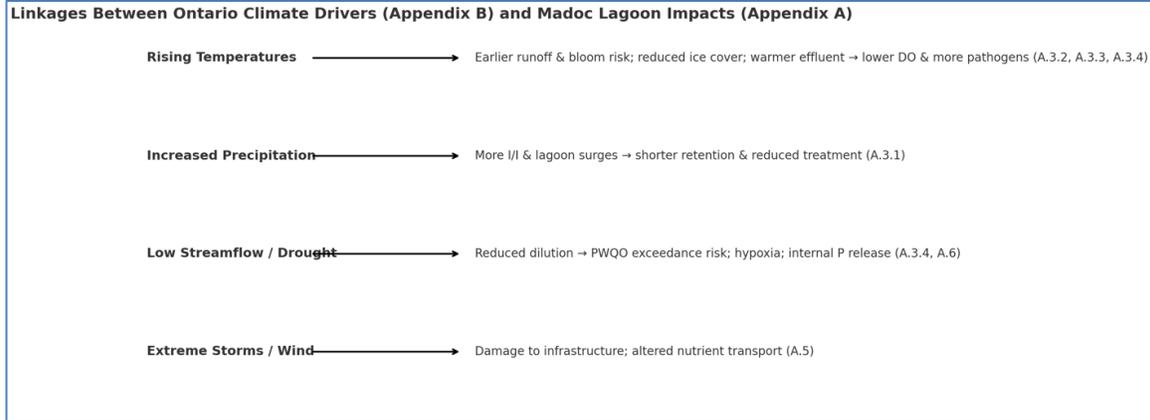
- The May 2022 derecho event in Hastings County illustrates the growing risk of extreme windstorms.
- These events can mobilize debris and sediment in water bodies, alter shoreline nutrient dynamics, and damage treatment infrastructure.

Implications:

- While direct effects on lagoon water quality may be short-term, extreme wind events can indirectly affect nutrient transport to Moira Lake and damage aeration, pumping, or control infrastructure (See *Appendix A.5 – Scenario Analysis – Operational Implications*).

A3.4 Summary

Ontario’s climate trends—rising temperatures, more intense precipitation, episodic drought, and extreme wind events—are consistent with the operational risks identified for the Madoc Lagoon in Appendix A.



The combination of these changes underscores the importance of adaptive management, flexible discharge timing, and enhanced monitoring to maintain compliance and protect Moira Lake’s ecological health.

Appendix 4: Glossary of Technical Terms

1. **Algal Biomass:** The mass of algae present in a water body, often used as an indicator of nutrient enrichment and eutrophication.
2. **Biochemical Oxygen Demand (BOD5/CBOD5):** A measure of the amount of oxygen required by microorganisms to break down organic matter in water over five days. CBOD5 (Carbonaceous BOD) excludes oxygen demand from nitrogenous compounds.
3. **Chemical Oxygen Demand (COD):** The total amount of oxygen required to oxidize both biodegradable and non-biodegradable organic compounds in water.
4. **Chlorophyll-a:** A pigment found in algae and other photosynthetic organisms, used as a proxy for algal biomass and an indicator of nutrient enrichment in aquatic ecosystems.
5. **Emerging Contaminants:** Pollutants such as pharmaceuticals, microplastics, and endocrine-disrupting chemicals that are not routinely monitored but pose potential risks to ecosystems and human health.
6. **Enterococci:** A group of bacteria used as indicators of fecal contamination and waterborne pathogens in recreational water quality testing.
7. **Eutrophication:** The process by which a body of water becomes overly enriched with nutrients, leading to excessive growth of algae and plants, oxygen depletion, and harm to aquatic life.
8. **Groundwater Monitoring:** Testing of water in underground aquifers to detect contamination from nutrients, pathogens, or other pollutants that may seep from nearby sources.
9. **Microplastics:** Small plastic particles (less than 5 mm) that originate from consumer products or industrial processes and persist in the environment, posing risks to aquatic life.
10. **Nitrogen Speciation:** The analysis of different forms of nitrogen in water, including ammonia, nitrate, and nitrite, to understand nutrient dynamics and potential ecological impacts.

11. **Nutrient Loading:** The input of nutrients, such as nitrogen and phosphorus, into a water body from sources like agricultural runoff or wastewater, often contributing to eutrophication.
12. **Pathogen Indicators:** Microorganisms, such as E. coli and Enterococci, used to assess the presence of harmful pathogens in water and evaluate public health risks.
13. **Phosphorus Speciation:** The analysis of different forms of phosphorus, such as total phosphorus and Soluble Reactive Phosphorus (SRP), to assess bioavailability and eutrophication risk.
14. **Soluble Reactive Phosphorus (SRP):** The bioavailable form of phosphorus that is directly usable by algae and aquatic plants, often contributing to algal blooms.
15. **Total Suspended Solids (TSS):** The concentration of solid particles suspended in water, including organic and inorganic matter, used as an indicator of water clarity and treatment effectiveness.
16. **Toxicity Testing (Bioassays):** Experiments conducted to assess the combined toxic effects of pollutants in water on living organisms, such as fish or invertebrates.